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**FORMERLY UTILIZED MED/AEC SITES
REMEDIAL ACTION PROGRAM
POST-REMEDIAL-ACTION RADIOLOGICAL SURVEY
OF
KENT CHEMICAL LABORATORY
THE UNIVERSITY OF CHICAGO
CHICAGO, ILLINOIS
May 1983**

**OCCUPATIONAL HEALTH AND SAFETY DIVISION
Health Physics Section**

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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Prepared by

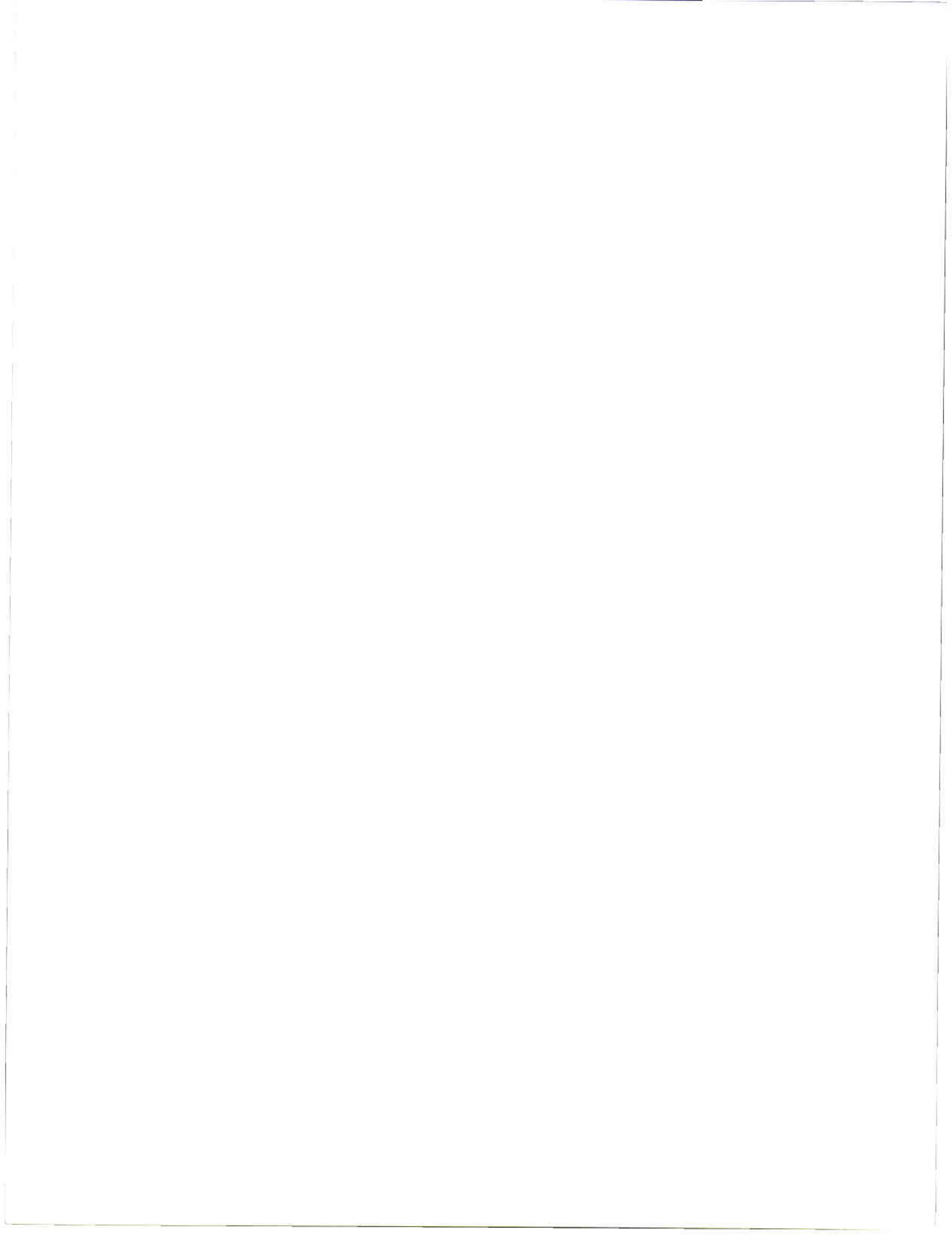
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PREFACE AND EXECUTIVE SUMMARY

Starting in January 1941, the University of Chicago contracted with the Federal Government to perform various research and development activities, that involved radioactive materials, namely uranium. These activities, which were first under the auspices of the National Defense Research Committee and then successively the Office of Scientific Research and Development, the Manhattan Engineer District and the Atomic Energy Commission, continued on the university campus until early in the 1950's. At that time, most research involving radioactive materials was transferred from the campus to the Argonne National Laboratory site in nearby DuPage County, Illinois.

One of the University of Chicago campus facilities in which radioactive materials were handled in the 1940s and 1950s, was the Kent Chemical Laboratory. When records of the U.S. Energy Research and Development Administration (ERDA), a successor to the AEC, were searched in the early 1970s, it was found that documentation was insufficient to determine if the decontamination work carried out at the Kent Chemical Laboratory when nuclear activities ceased was adequate by current guidelines. Consequently, a comprehensive radiological assessment of Kent Laboratory was conducted during September 1977, by the ANL Radiological Survey Group¹ to determine if any radioactive contamination remained. The results of the assessment indicated the need for remedial action.

Since 1977, the University has decontaminated this laboratory building, and in May 1983, the Department of Energy (DOE) requested the ANL Radiological Survey Group to conduct a post-remedial-action survey. All the contaminated areas identified during the 1977 assessment were rechecked. Contamination remained in six of the rooms. Further decontamination of these areas was conducted by university personnel, and as a result, these areas are now free of contamination. However, a contaminated clay pipe in the attic remained. The clay pipe has since been removed and disposed of as solid radioactive waste.

During the post-remedial-action survey, six soil samples were collected from excavation trenches dug in Rooms 1 and 2 as part of the University's remedial action efforts. Also, four sludge samples were taken from below the manhole covers in the basement of Kent Chemical Laboratory to assess the radiological condition of the sewer system. A radiological assessment of the sewer system had not been accomplished during the 1977 survey as per program direction.

Radiochemical (fluorometric) and gamma-spectral analyses indicated that eight out of ten soil and sludge samples contained levels of radioactivity above expected background concentrations. The soil has since been further excavated.

The building is now free of radioactive contamination in excess of background levels; however, the sewers do contain radioactive materials above background levels since contamination was found at appropriate access points.

This survey was performed by the following Health Physics personnel of the Occupational Health and Safety Division, Argonne National Laboratory, Argonne, Illinois: W. H. Smith, K. F. Flynn, A. L. Justus, C. M. Sholeen, J. D. Thereon, and D. W. Reilly.

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FORMERLY UTILIZED MED/AEC SITES REMEDIAL ACTION PROGRAM
POST-REMEDIAL-ACTION RADIOLOGICAL SURVEY
OF
KENT CHEMICAL LABORATORY
UNIVERSITY OF CHICAGO, CHICAGO, ILLINOIS

INTRODUCTION

During 1939 and 1940, U.S. interest in nuclear physics increased as a result of recent discoveries, the war in Europe, and the possibility of developing an atomic bomb. During this time, the National Defense Research Committee (NDRC) was interested in constructing uranium piles that would maintain self-sustaining nuclear chain reactions. In January 1941, the NDRC contracted for the University of Chicago to make measurements on beryllium as a moderator in a uranium pile.

When the United States entered WW-II in December 1941, the research was reorganized and the Office of Scientific Research and Development (OSRD) became responsible for all work related to nuclear chain reactions, and all emphasis was centered on production of an atomic bomb. The OSRD established a committee, the S-1 committee, to assume the responsibility for scientific studies and measurements necessary to develop an atomic bomb. Members of the committee accepted responsibility for various aspects of the project. Dr. Arthur Compton, a professor at the University of Chicago, was responsible for the theoretical studies and experimental measurements necessary to produce element 94 (plutonium) for the bomb. Therefore, in January 1942, a contract was initiated between the university and OSRD. Between January and the end of May 1942, pile experiments from Columbia University and Princeton University were transferred to the Metallurgical Laboratory (Met Lab), which was created on the University of Chicago campus.

Plutonium is produced when neutrons are absorbed by uranium. To produce the large quantities of plutonium needed for the bomb, an intense source of neutrons was needed. Only uranium piles offered the possibility of creating this neutron source by producing a self-sustaining nuclear chain reaction. The first pile that was large enough to sustain the chain reaction was composed of

uranium and graphite. It was constructed beneath the west stands of Stagg Field under the direction of Dr. Enrico Fermi. The self-sustaining condition was finally achieved on December 2, 1942.

During 1942, Dr. Compton also transferred all work on the development of methods for the purification of plutonium to the Met Lab. In April 1942, Dr. Glenn Seaborg arrived in Chicago with a group from the University of California at Berkeley to continue their chemical work on element 94 separation and purification. The work on plutonium chemistry and pile experiments was conducted exclusively at the University of Chicago, including the Kent Chemical Laboratory, until the winter of 1943. At that time, the Clinton Laboratories (now Oak Ridge National Laboratory) started their pilot plant.

The Army Corps of Engineers took over responsibility for the bomb development and production by June 1942. Their organization was called the Manhattan Engineer District (MED). After the feasibility of producing plutonium had been demonstrated, the contract with the Met Lab was transferred from OSRD to MED on May 15, 1943. Experimental work continued under MED until 1946, when the Atomic Energy Commission (AEC), a civilian organization, was created.² At that time the laboratory's name was changed from the Met Lab to Argonne National Laboratory (ANL). Work under the AEC contract continued through 1952, when most of the activities were moved from the University of Chicago to the new Argonne National Laboratory site in DuPage County.³

Several facilities on the University of Chicago campus were used in the research programs involving radioactivity; one such facility was the Kent Chemical Laboratory. In the 1970s, no records could be found of radiation surveys or decontamination efforts being conducted at Kent Chemical Laboratory after termination of MED/AEC activities. Therefore, the U.S. Department of Energy (DOE) directed the Argonne National Laboratory (ANL) Radiological Survey Group (RSG) to perform a radiation survey of the Kent Laboratory to determine if any detectable radioactive contamination remained. The survey was performed during September 1977, and the results, as reported in an earlier document,¹ indicated that some remedial action was needed in order to meet current radioactive material contamination guidelines.

In response to those findings, the University of Chicago performed decontamination efforts at the Kent Chemical Laboratory prior to and concurrent with some facility renovations. The ANL/RSG was then requested to conduct a post-remedial-action survey in May 1983. The post-remedial-action survey and the results thereof are described in this report.

The Kent Chemical Laboratory is located in Chicago (see Fig. 1) near Ellis Avenue and East 58th Street on the University of Chicago campus (see Fig. 2). The building consists of three floors, a basement and an attic, as shown in Figures 3 through 6.

SURVEY AND ANALYTICAL PROCEDURES

General

The post-remedial-action radiological survey conducted by ANL in May 1983, included the nineteen contaminated areas found during the survey in 1977 (as reported in Reference 1). During the 1977 survey, ten contaminated floor areas were identified in Rooms 1, 2, 4, 14, and 18 of the basement, and Rooms 101, 201, 209, and 305 on upper floors. In all cases, beta-gamma contamination was between 6.4×10^2 and 1.8×10^4 dis/min-100 cm². A few of these areas also had alpha contamination ranging up to 1.3×10^4 dis/min-100 cm² by direct readings (removable alpha contamination ranged up to 18 dis/min-100 cm²). Eight contaminated wall areas were identified in the 1977 survey--three in Room 101, one in Room 102, two in Room 109, and two in Room 209. At all these locations, beta-gamma contamination was between 5.8×10^3 and 8.0×10^5 dis/min-100 cm² as measured by direct readings. These areas also had contact exposure rates above the background level, ranging between 0.06 and 70 mR/h. The final contaminated item was a clay tile vent pipe in the floor of the attic. The pipe had alpha and beta-gamma contamination of 6.4×10^3 cts/min-100 cm² and 1.7×10^4 cts/min-100 cm², respectively, as measured by direct readings. This was the only area that gave a beta-gamma smear reading above the measured background. The smear indicated 98 dis/min-100 cm² beta-gamma, with an alpha reading of 92 dis/min-100 cm².

Because of program direction for radiological assessment in 1977, equipment in the building was not moved, and the sewers were not surveyed. The subsequent remedial action involved removal of the contamination on the concrete and wood floors and brick walls. Decontamination of small areas involved chipping the host material. For larger areas of contamination, remedial action involved removing concrete and soil (as in Rooms 1 and 2), removing bricks from the wall (as in Rooms 101, 109 and 209), and removal of the tile, wood, and insulation

(as in Rooms 101 and 209). The remedial action required surveying below equipment and benches, as well as continual surveying during decontamination.

Instrumentation

Four types of portable survey instruments were used to conduct the post-remedial-action direct radiological surveys. Propane gas-flow proportional detectors with window areas of 51 cm² and 100 cm² (using Eberline PAC-4G-3 electronics) were used to monitor for alpha and/or beta-gamma radiation. NaI crystal detectors, 5-cm (2-in) diameter by 2-mm thick (Eberline PG-2 with Eberline PRM-5-3 electronics), were used to monitor for low energy x-ray and gamma radiation. NaI crystal detectors, measuring 2.5-cm (1-in) diameter by 2.5-cm (1-in) thick (Eberline PRM-7 μ R meter) and calibrated with a ²²⁶Ra standard source, were used to measure the ambient external penetrating radiation field in units of μ R/h. An end-window Geiger-Mueller (GM) detector (Eberline HP-190 with a 7 mg/cm² window and Eberline 530 electronics), calibrated with a ²²⁶Ra standard source, was used to measure the contact exposure rate (mR/h) of contaminated areas. All four instruments used in this survey are described in more detail in Appendix 1 as are other instruments having site-specific applications for similar surveys.

Although ²³⁹Pu and ⁹⁰Sr-⁹⁰Y standards were used to calibrate the gas-flow instruments, it should be noted that the numerous isotopes that could be encountered exhibit emission energies differing from those of the standards used in the calibration. For the purpose of this survey, a conversion factor for normal uranium was used to determine the appropriate surface contamination. The methods used to determine the conversion factors are described in Appendix 2. Since instrument calibrations were to flat-plate infinitely thin ²³⁹Pu and ⁹⁰Sr-⁹⁰Y standards, all reported readings should be regarded as minimal values; no corrections were made for absorption by surface media.

Whenever possible, a contaminant was identified by performing gamma spectral analysis on either the contaminated item or on a sample of material taken from a contaminated area. A sodium iodide detector coupled to a multichannel analyzer was used for this purpose.

Air Samples

Air particulate ("grab") samples were collected using an ANL-modified, commercial vacuum cleaner to pull air through the filter medium (HV-70). A total volume of 26.7 m³ of air was sampled at a flow rate of 40 cubic meters per hour (m³/h). A 10% portion (5 cm in diameter) of the filter media was removed after sample collection and counted for both alpha and beta-gamma activity in a 2 π internal gas-flow counter (PC counter), using a double-aluminized Mylar window (Mylar spun top) ~ 0.85 mg/cm². Concentrations of radon (²²²Rn) daughters and thoron (²²⁰Rn) daughters and the concentration of any long-lived airborne radionuclides were determined based on the result of several counts of each sample at specified intervals. Information and assumptions used to determine the concentrations are presented in Appendix 3.

Air particulate samples were also collected on Millipore membrane filter media for 40 minutes at a flow rate of approximately 1.2 m³/h. A portion of each filter sample was used for alpha spectral analysis to determine the actinon (²¹⁹Rn) daughter to radon (²²²Rn) daughter ratio.

Grab air samples were also collected in 0.5-l Eberline scintillation cells. Evacuated cells were taken into several rooms and the vacuum drew air through glass-fiber filter paper. The air sample was allowed to equilibrate for more than three hours before the sample was counted for 30 or 60 minutes to determine the radon gas concentration.

Soil and Sewer Samples

During the decontamination of the floor in Rooms 1 and 2, concrete and soil were removed. Thus, when members of the ANL/RSG arrived, there was an excavation trench from Room 1 to Room 2. Six soil samples were collected from this excavation.

During the 1977 survey, DOE Headquarters had indicated that the survey of the sewer system should be postponed until the decontamination stage. Therefore, in accordance with that direction, during the post-remedial-action survey, the four manhole covers in the basement of Kent Chemical Laboratory were removed and a sludge sample was taken from each hole.

The soil and sludge samples were prepared for analysis by weighing each sample in its "as collected" state, drying it for approximately 48 hours at

80° C, and then reweighing the sample to determine dry weight. Each sample was then put into mill jars (8.7 l), and milled for up to two hours. At no time were any rocks crushed, ground or pulverized, since this would act to dilute, and hence lower, the reported concentration of deposited radioactive material. After sufficient milling, the sample material was sieved. Each fraction (rocks and dross vs. fines) was bagged and weighed separately.

Weighed aliquots of the fines were then loaded into screwtop plastic containers for analysis. Aliquots of 100 g, if available, were prepared for gamma-spectral analysis, and 5 g for radiochemical (fluorometric) analysis (see Fig. 7). Every effort was made during sample preparation to prevent cross-contamination. Soil samples suspected of containing elevated levels of radioactivity were processed in equipment separate from the soil samples considered to contain background levels. All processing equipment was scrubbed and air dried before introduction of the next sample.

The samples were submitted to the Analytical Chemistry Section of the Chemical Engineering Division at Argonne National Laboratory for radiochemical analysis of uranium content (fluorometric) and gamma-spectral analysis. This included quantification of the ^{226}Ra chain and the ^{232}Th chain. Two samples were also analyzed for the atom percent abundance of uranium isotopes (mass spectrometry). The procedures used for soil analysis are described in Appendix 4.

RADIOLOGICAL SURVEY RESULTS

General

The PAC-4G-3 instrument readings were made with a 100-cm²-window-area probe designed at ANL. In this report, the readings are equated to normal uranium. The readings are reported in Table 1 in net count rates, i.e., the background count rates have been subtracted from the gross count rates prior to conversion to dis/min-100 cm². Since all alpha readings were measured at the background level, it was not necessary to correct for alpha contribution to the beta-gamma readings.

The readings with the GM end-window, the μR meter, and the PRM-5-3, are reported as gross mR/h, $\mu\text{R}/\text{h}$, and cts/min respectively. The background levels varied somewhat as expected. The average background readings for all instruments used in the survey are given in Appendix 1.

Instrument Survey

During the 1983 post-remedial-action survey, the contaminated areas detected in the 1977 survey were all checked, and the results indicated that areas in six of the rooms still were contaminated with radioactivity above background levels

In Rooms 1 and 2 (see Figs. 8 and 9), part of the concrete floor had been removed as indicated in Figure 3, and soil had been removed down to a depth of 2 ft. Portable instrument measurements of residual soil contamination are presented in Table 1. The maximum reading came from a dirt pile in Room 2 beside the excavation site. The PAC-4G-3 indicated beta-gamma contamination of up to 5400 dis/min-100 cm² above background equated to normal uranium. The entire dirt pile was discarded as solid radioactive waste (SRW).

Six soil samples were taken from the excavated area in Rooms 1 and 2 (Fig. 3) for radiochemical and gamma-spectral analysis at ANL since the portable instruments do not give as sensitive an indication of soil concentration. The four manhole covers in the basement of Kent Laboratory were opened as shown in Figure 10 and a sludge sample was collected from the bottom of each hole in order that a more sensitive determination by radiochemical and gamma spectral analysis could be made. The portable instruments, used to survey these holes, all read background levels. However, these readings cannot be used to conclude that the sewers are not contaminated since the access points are restricted and only gross contamination can be expected to be seen on these instruments.

Residual contamination was found on the walls and floors of Rooms 101, 109, and 209, and in a clay vent pipe in the attic. In the three rooms, residual contamination was found adjacent to areas that had been decontaminated. The gross instrument readings are given in Table 1. The vent pipe gave a maximum beta-gamma reading of 9.2×10^3 dis/min-100 cm² as equated to ⁹⁰Sr-⁹⁰Y and Location 5 in Room 109 gave a maximum beta-gamma reading of 1.1×10^4 dis/min-100 cm² as equated to normal uranium. As a result of these findings, additional decontamination effort was undertaken by University of Chicago personnel. As a consequence of this additional effort, all contaminated walls and floors were decontaminated to background levels before the ANL/RSG members completed their survey. The decontaminated areas are shown in Figures 11 through 14.

The clay ventilation pipe in the attic was not decontaminated at that time because it was built into the wall between Rooms 304 and 305 on the third floor (see Figs. 6 and 15). After removal of the top section of clay pipe in the attic, the PG-2 probe of the PRM-5-3 instrument was lowered about 2 ft into the remaining pipe, and a reading of 1.0×10^4 cts/min, including a 2.5×10^3 cts/min background, was obtained. Before leaving the site, the ANL/RSG recommended that health physics practices and coverage be utilized during removal of the clay vent pipe and that it be disposed of as SRW.

Although background radiation levels were measured in the sewers during the portable instrument survey, health physics coverage also was recommended during the excavation in the basement and removal of the sewer pipe because of the limited accessibility of the sewers for radiological survey.

On June 9, 1983, health physics representatives from the University of Chicago reported that the contaminated clay ventilation pipe visible in the attic terminated on the third floor. The entire pipe was removed by university personnel and disposed of as SRW. University health physics representatives reported that some of the sewer pipes were also surveyed, as recommended, with their portable instruments during the remodeling. University personnel indicated that instrument readings of the outside of these sewer pipes showed no radiation levels above background. However, since there may have been low levels of sewer contamination that were not detected by this survey method, as a precaution, the sewer pipes were discarded as radioactive waste.

Air Samples

The radon (^{222}Rn) concentrations, Working Level (WL), and thoron (^{220}Rn) concentrations determined from the two air samples collected according to the ANL method described in Appendix 1 and calculated as described in Appendix 3 are given in columns 5, 6, and 7 of Table 2. The radon concentrations determined from the five air samples collected using the scintillation cells (as described in Appendix 1), are given in Column 9 of the table. The results of the two different sample-collection methods used in Rooms 1 and 2 are in agreement within the degree of uncertainty of the numbers as calculated from the square root of the total counts for each sample. The radon-daughter Working Levels of 2.9×10^{-4} WL and 7.5×10^{-4} WL were well below the criterion of 0.01 WL above

background as specified in the U.S. Surgeon General's Guidelines as included in 10 CFR 712. The radon concentrations, ranging from 0.06 ± 0.02 to 0.22 ± 0.07 pCi/l, were also below the 3 pCi/l requirement for radiation protection specified in DOE 5480.1, Chapter XI. The thoron concentrations, ranging up to 0.0038 pCi/l, were below the 10 pCi/l requirement given in DOE 5480.1 (see Appendix 6). No actinon daughter concentration or long-lived airborne radionuclide concentration above the limits of detection was observed.

Soil Samples

All soil samples (numbered KC-S4 through KC-S9), were collected to a 2-in. to 3-in. depth. Sample weights are given in Table 3, and the analyses results are given in Table 4. Background soil sample data from the northern Illinois area are given in Table 5. The analyses results of three environmental samples taken during the 1977 survey are given in Table 6. The environmental samples were collected using a 4-in. diameter, 6-in. long, right-circular-cylinder cutting tool commonly used to cut holes on golf greens. Each soil core was 12 in. long and was divided into four segments for analysis. Starting from the surface, three 2-in segments were cut, bagged, and marked A, B, and C respectively; the final segment of 6 in was marked D. The sample locations are shown in Figure 16. The concentrations of radioisotopes in these samples were all background levels.

The maximum readings with the portable instruments were obtained in the dirt piled beside the trench in Room 2. The sample from this pile is KC-S8. However, as seen in Table 4, the maximum uranium concentration based on laboratory analysis occurred in the trenches where samples KC-S5, KC-S7 and KC-S9 were taken. The mass spectrometric analysis of KC-S5 indicated normal uranium. Table 7 indicates uranium isotopic abundances that are identical to the abundances found in nature; however, Table 4 indicates the uranium has been separated from its daughter products (^{226}Ra decay chain). It, therefore, is concluded that the soil was contaminated with normal uranium since these analyses are the only sensitive methods for assessing the radiological condition of the soil.

Sewer Sludge

As indicated in Table 4, three of the four sludge samples collected from the sewers in the basement of Kent Chemical Laboratory show elevated levels of uranium. Based on the ^{226}Ra decay chain and uranium concentrations in Table 4 and the isotopic abundances listed found in Table 7, it is concluded that the sewers are contaminated with normal uranium. Since these radiochemical and gamma spectrometric analyses are the most sensitive methods of assessing the radiological condition of the sewers, it must be concluded from the results of these analyses that the sewer lines are contaminated as specified in the NRC guidelines dated July 1982.

Ventilation Pipe

A piece of the contaminated clay ventilation pipe removed and analyzed by University of Chicago health physics personnel was found to contain uranium and thorium. The pipe was then transported to ANL for further analysis. The results, presented in Table 4, indicate that the uranium and thorium detected in the University of Chicago analysis are primarily natural components of the clay rather than contamination resulting from MED/AEC activity. The survey in 1977¹ and surveys of the pipe piece analyzed by ANL Analytical Chemistry Laboratory (see Table 1) indicated that the radioactivity detected was from both alpha and beta emitters. Since the gamma spectral analysis failed to identify the contamination, the emitters were equated to be ^{239}Pu for the alpha and ^{90}Sr - ^{90}Y for the beta in order to convert the PAC reading from cts/min to dis/min. Since the pipe has subsequently been removed by University of Chicago personnel and disposed of as solid radioactive waste, no further efforts to identify the contamination are deemed necessary.

CONCLUSIONS

Based on the results of the post-remedial-action survey and the analysis of the soil and sewer sludge samples, the following conclusions have been drawn:

1. Soil Contamination: Since there is no standard that directly pertains to soil contamination for this site, the results of the post-remedial-action

analysis were compared to the EPA Standard, 40 CFR Chapter I, Subchapter F, Part 192.12 for Uranium Mill Tailings (see Appendix 6). The soil samples listed in Table 4 were collected before the final removal of soil by the University of Chicago. After the final soil removal, portable instrument readings indicated that the levels of activity had been lowered through additional removal of dirt. The concentrations shown in Table 4 (which are higher than the final concentration of the remaining soil) when averaged over a large area (100 square meters) are well below the 15 pCi/g standard for radium-226. The values are also below the recommended limits of 40 pCi/g for uranium-238 and uranium-234 (from LA-UR-79-1865-Rev). Therefore, it is concluded that the soil in Rooms 1 and 2 have been satisfactorily cleaned up to meet this applied criterion.

2. Surface Contamination: The surface contamination in the Kent Chemical Laboratory has been cleaned to levels that are as low as reasonably achievable (ALARA) and meet the criteria specified in the Draft American National Standard N13.12 and the NRC "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source or Special Nuclear Material," dated July 1982.
3. Sewer Contamination: Contamination was found at accessible points in the sewer. Past experience of ANL Health Physicists indicates that contamination in other parts of the sewer can be even greater. The NRC "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source or Special Nuclear Material," dated July 1982, states:

"The radioactivity on the interior surfaces of pipes, drain lines, or ductwork shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, of ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but

are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits."

Therefore, based on these guidelines, the sewers remaining under the building are concluded to be contaminated in excess of the criteria.

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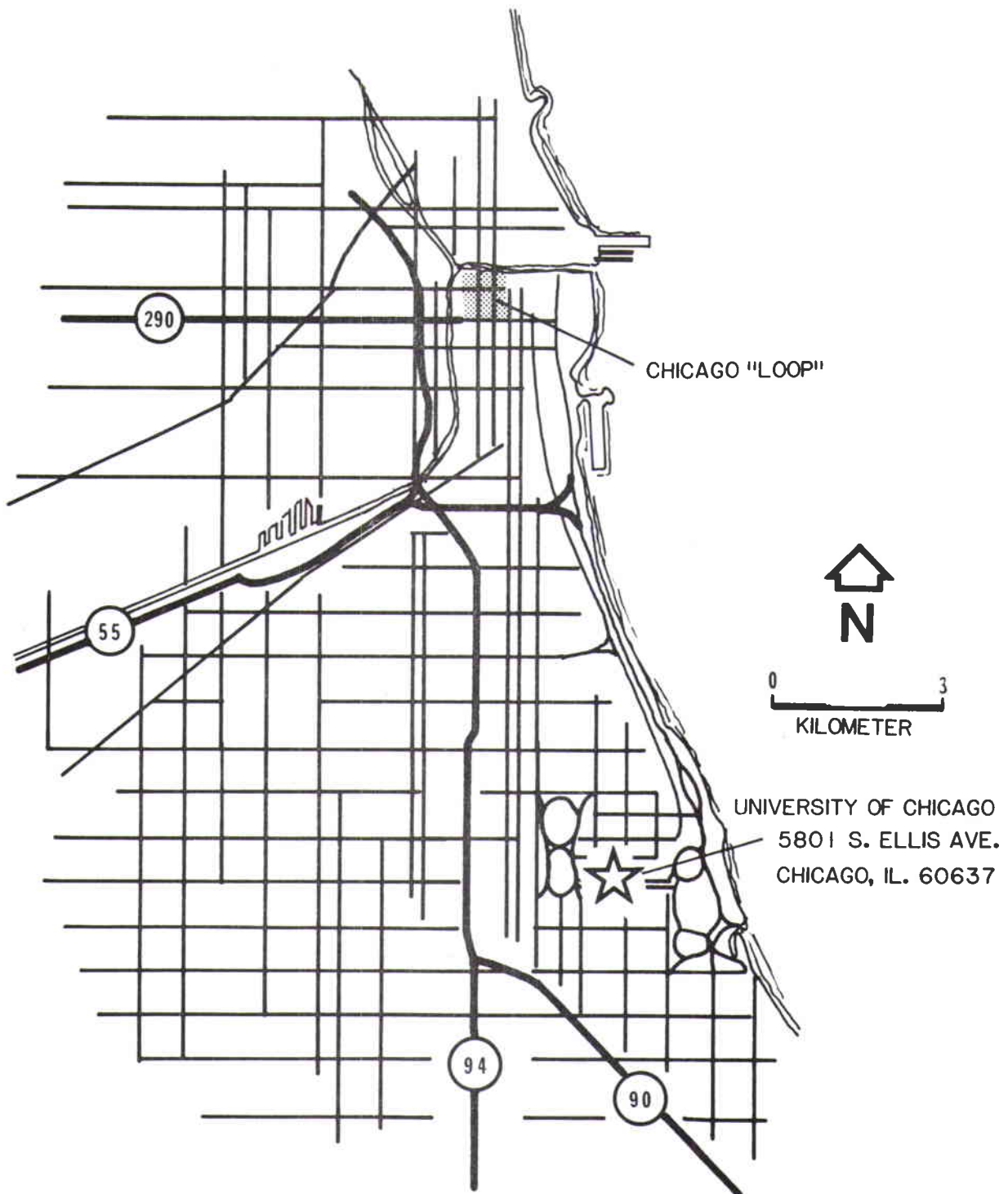


Figure 1. Site Location of The University of Chicago.
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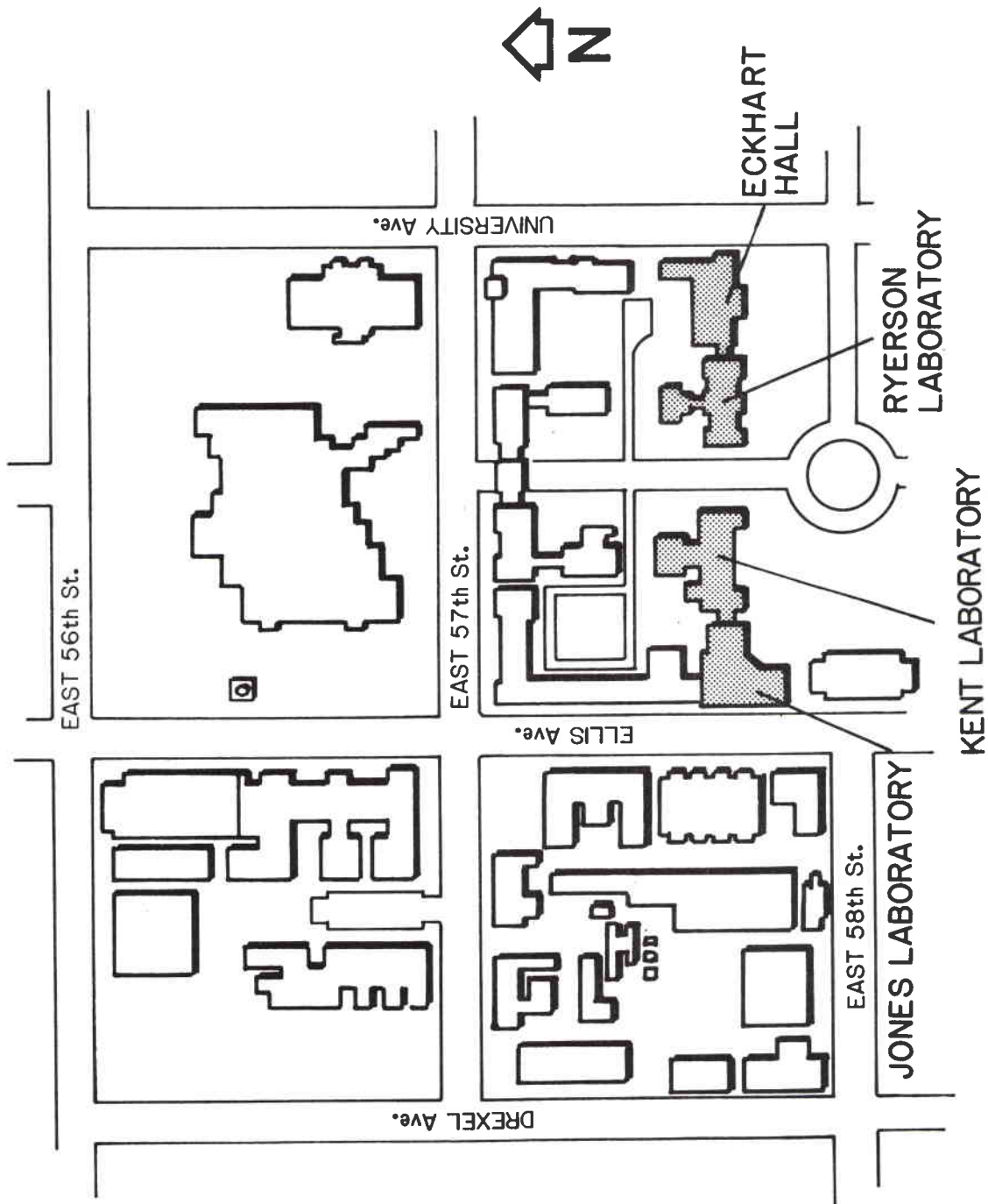


Figure 2. University of Chicago Campus.
ANL-HP Dwg. No. 83-42.

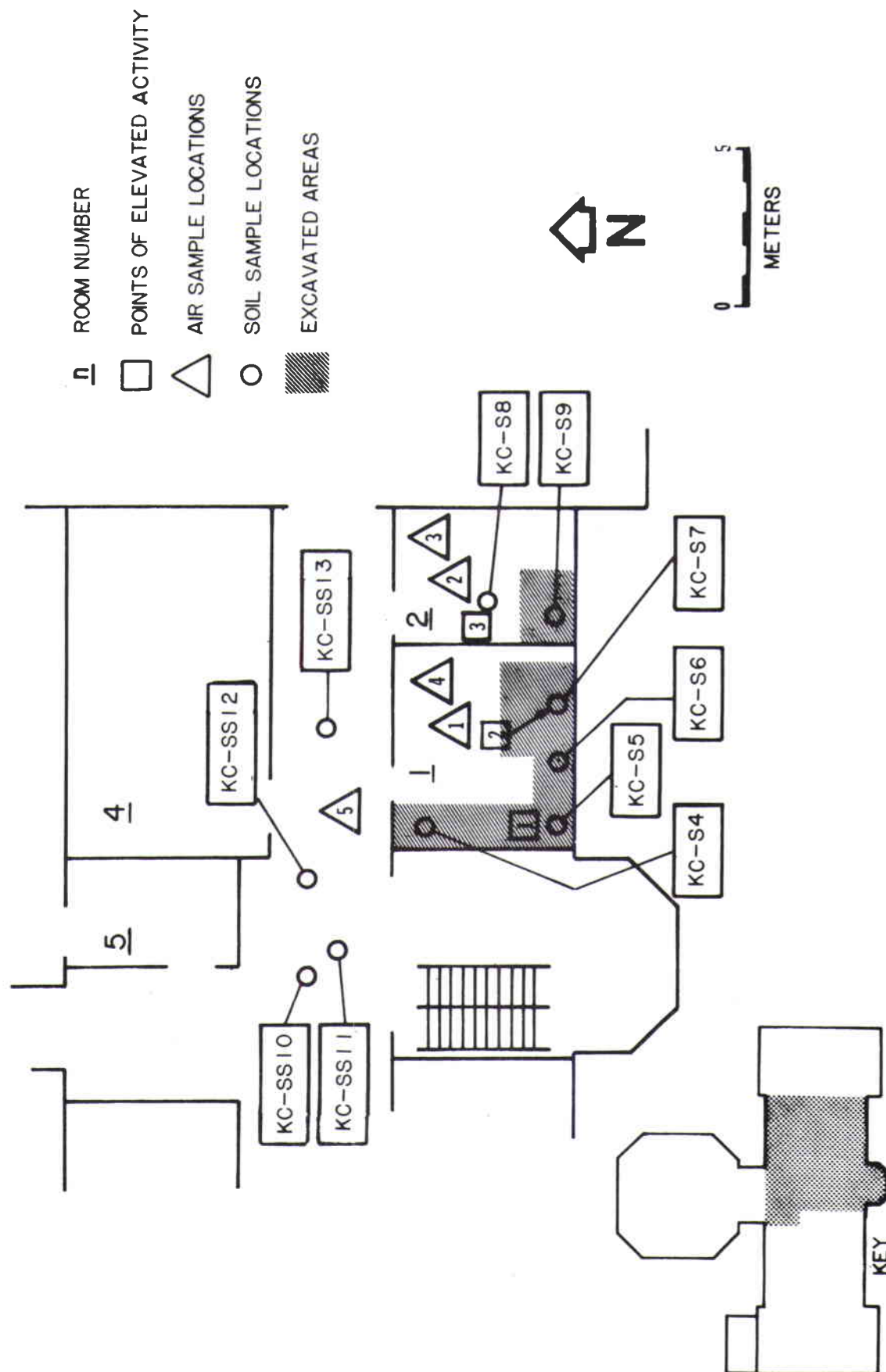


Figure 3. Kent Laboratory Basement.
ANL-HP Dwg. No. 83-44.

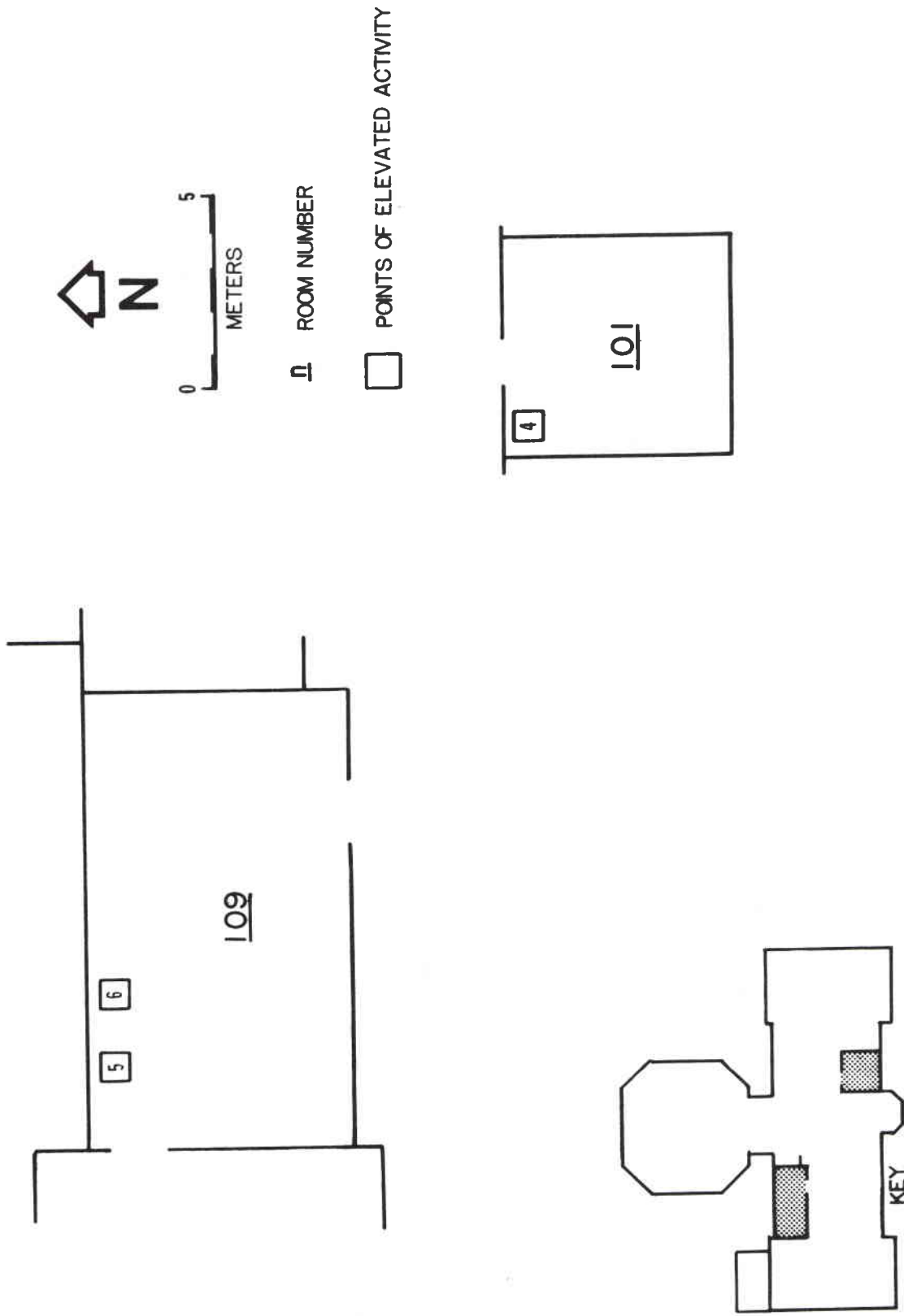


Figure 4. Kent Laboratory First Floor.
ANL-HP Dwg. No. 83-45.

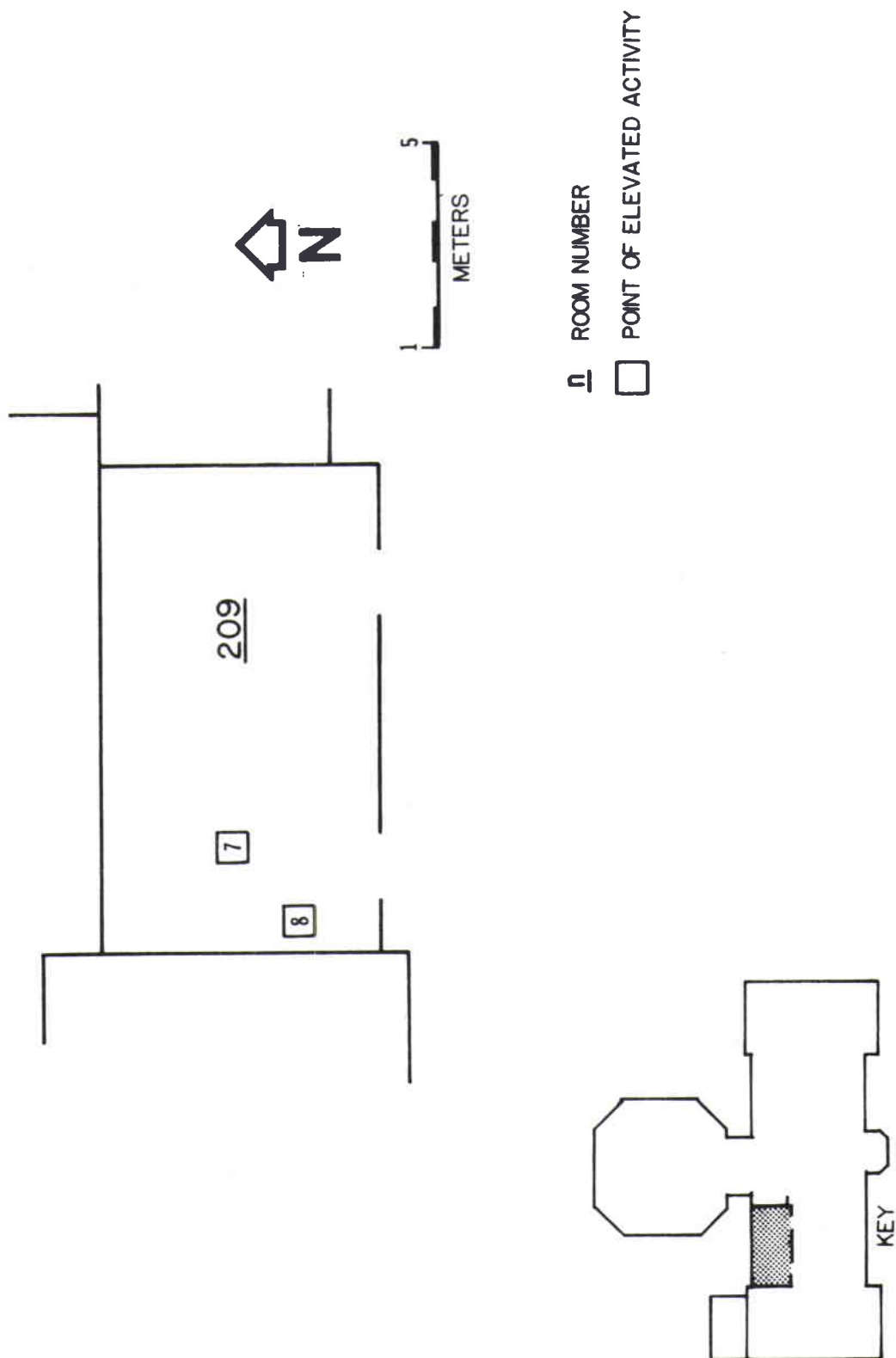


Figure 5. Kent Laboratory Second Floor.
ANL-HP Dwg. No. 83-46.

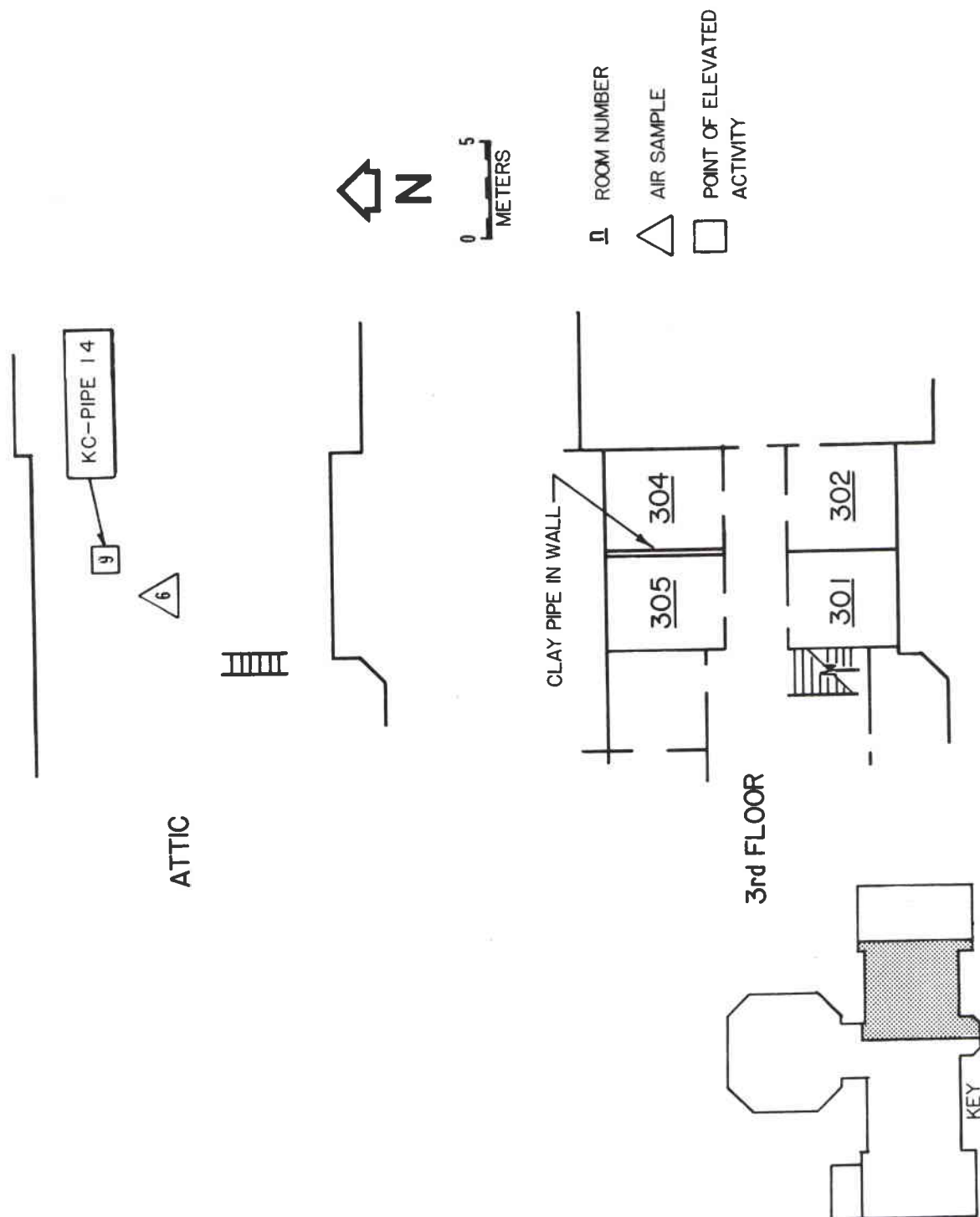


Figure 6. Kent Laboratory Third Floor and Attic.
ANL-HP Dwg. No. 83-47.

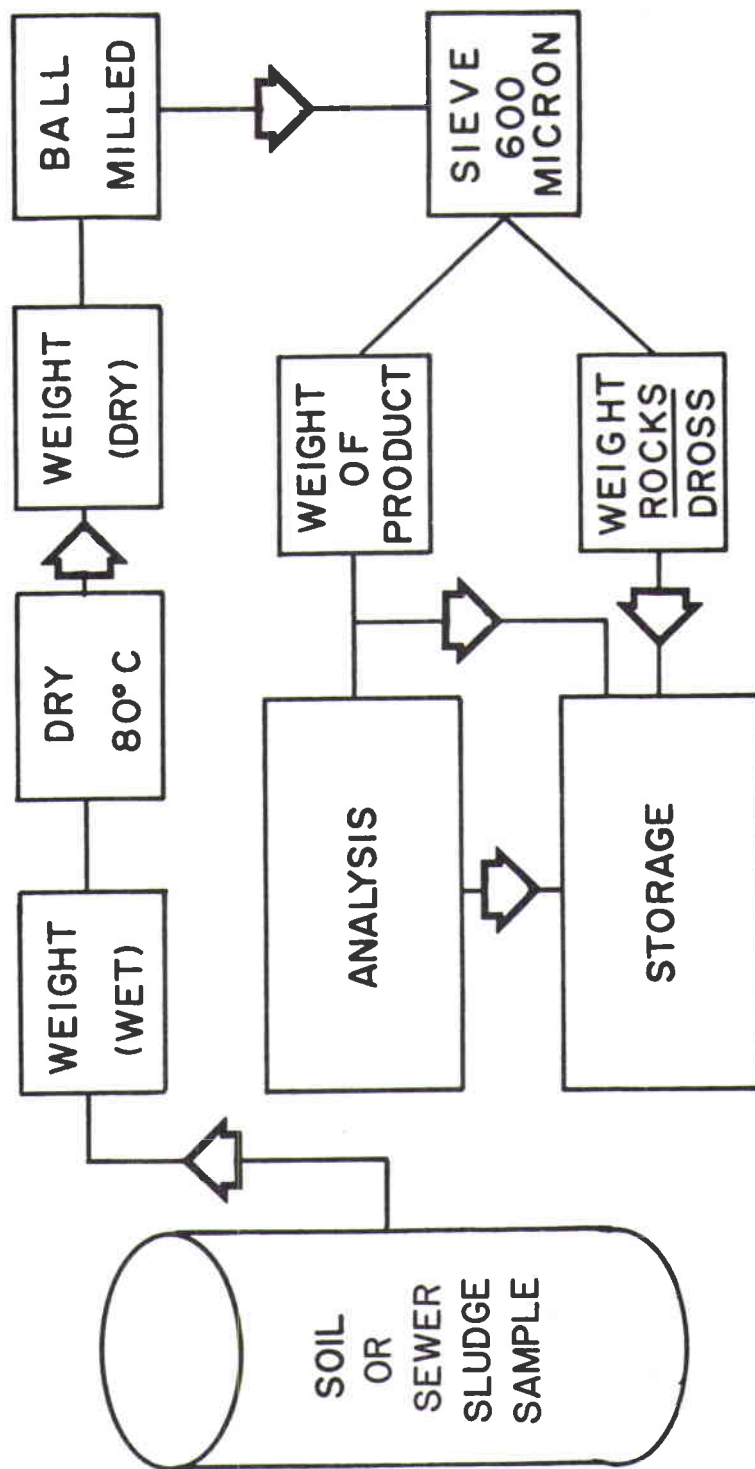


Figure 7. Soil and Sewer Sludge Sample Processing.
ANL-HP Dwg. No. 78-2.

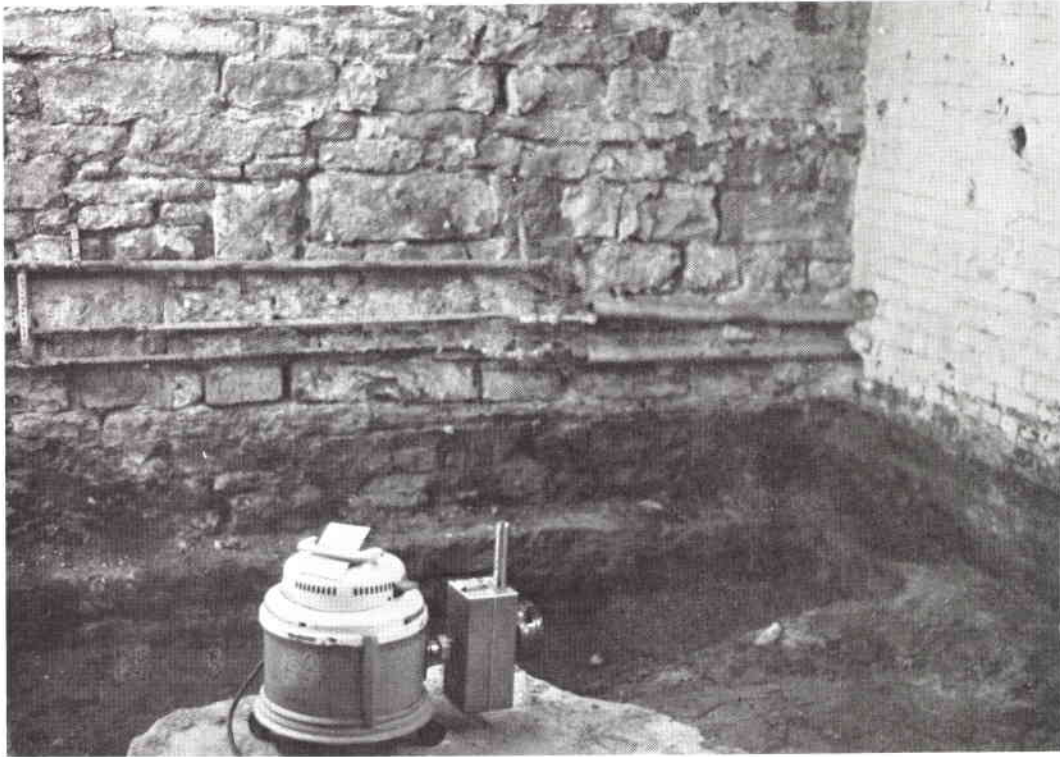


Figure 8. Floor of Room 1 after Decontamination.



Figure 9. Trench from Room 1 to Room 2.

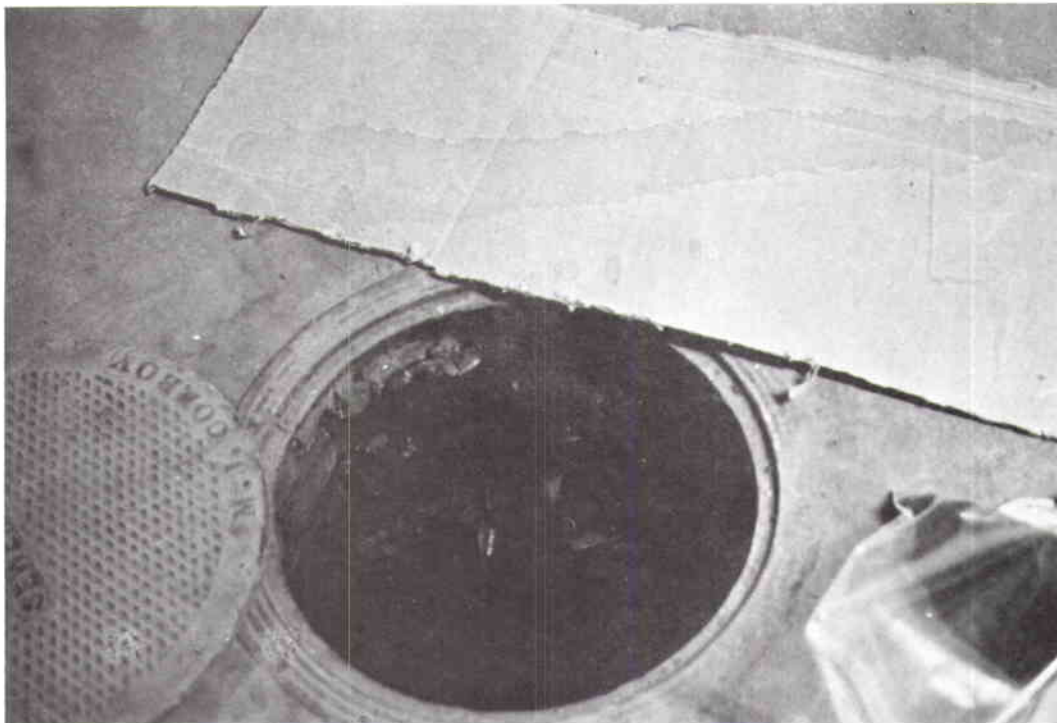


Figure 10. Sewer in Basement of Kent.

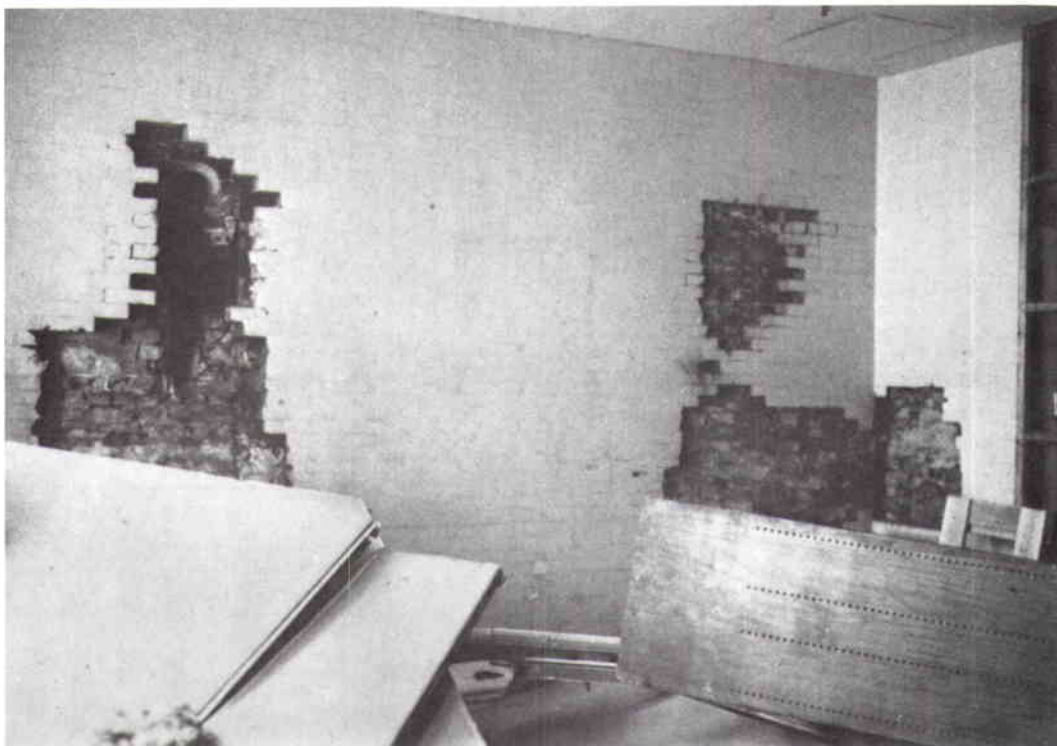


Figure 11. Wall of Room 101 after Decontamination.

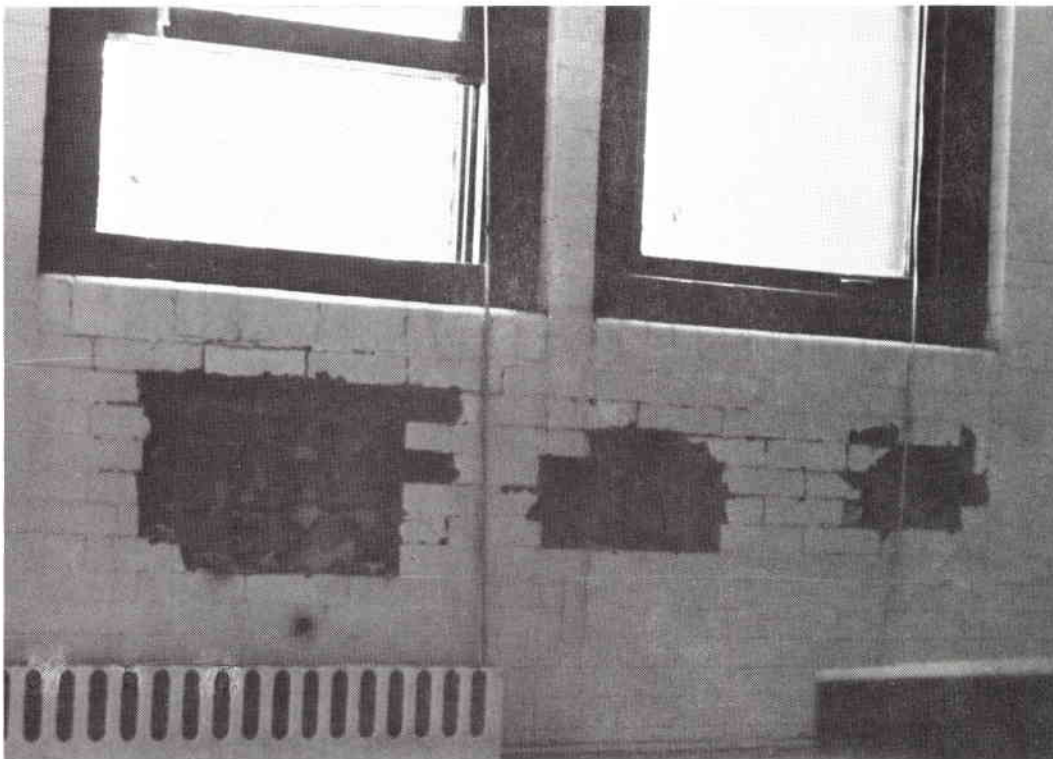


Figure 12. Wall of Room 109 after Decontamination.

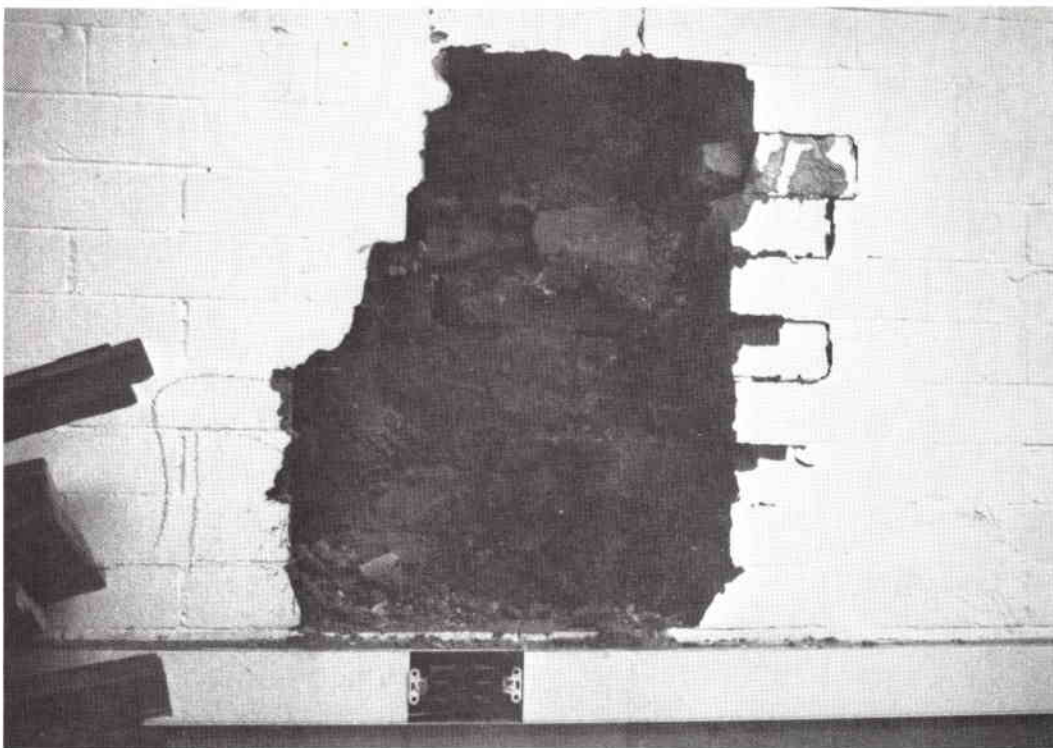


Figure 13. Wall of Room 209 after Decontamination.



Figure 14. Floor of Room 209 after Decontamination.

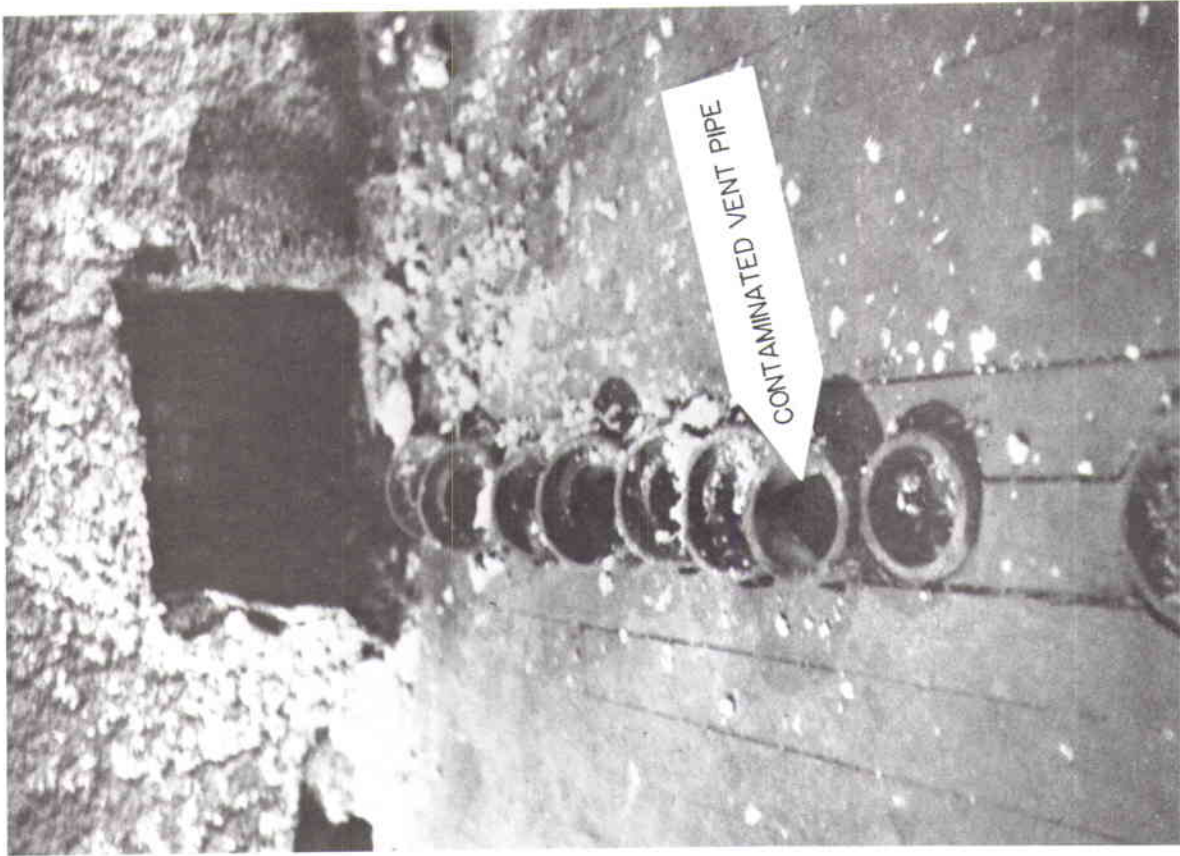


Figure 15. Pipes in Attic during Decontamination.

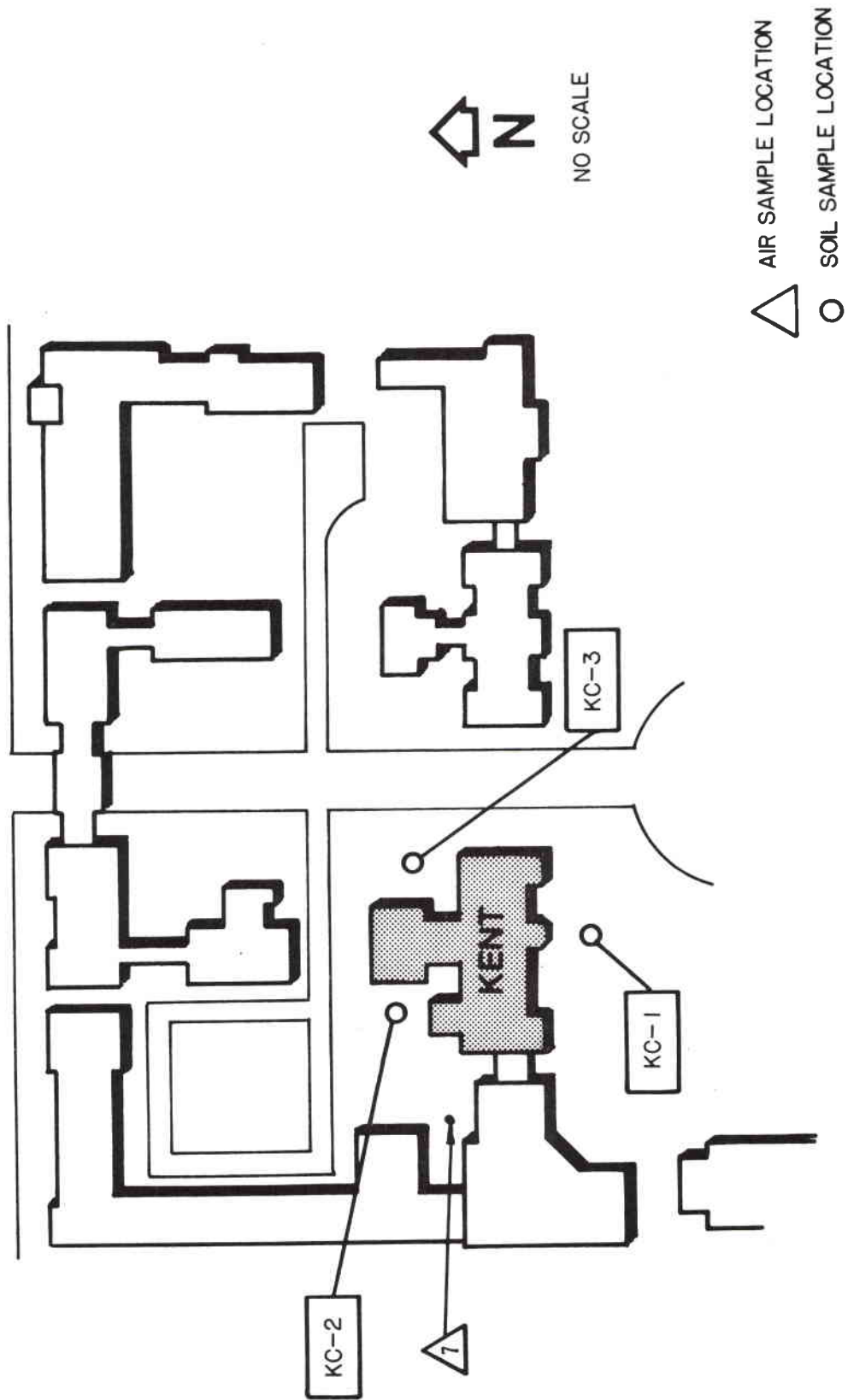


Figure 16. Kent Laboratory and Environs.

TABLE 1
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey Floor Wall	Air Sample (WL)	PAC 4G-3 Direct Readings ^a Beta Alpha	End Window GM (mR/h) Contact	PRM-7 (pR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
1		2.9x10 ⁻⁴	600 ^e	BKGD	BKGD	BKGD		Location 1 equated to normal U
2		7.5x10 ⁻⁴	1800	BKGD	BKGD	3500		Location 2 equated to normal U
4		NS ^b	5400	.05	17-20	4500		Dirt Pile Location 3
14		NS	BKGD	BKGD	BKGD	BKGD		
18		NS	360	BKGD	BKGD	BKGD		
101		NS	360	.05	20	4000		55-gallon drum "CAUSTIC POTASH"
109		NS	BKGD	BKGD	BKGD	BKGD		
		NS	4100	0.1	NRR ^f	4000		Location 4 equated to normal U
		NS	11000	0.15	NRR	4000		Location 5 equated to normal U
			NRR	NRR	NRR	3000		Location 6

TABLE 1
DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey		Air Sample (WL)	PAC 4G-3 Direct Readings ^a		End Window GM Contact	PRM-7 (μR/h) 1 meter	PRM-5-3 w/PG-2 (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall		Beta	Alpha					
201			NS	BKGD	NA	BKGD	BKGD	BKGD		Location 7 equated to normal U
209			NS	7700	1300	0.08	22	5000		
				5300	BKGD	0.04	NRR	3500		Location 8 (Wall) equated to normal U
305			NS	BKGD	NA	BKGD	BKGD	BKGD		
Attic			NS	9200	NRR	.06-.07	14	4000		7th vent from wall equated to Sr-Y
				750	800	NRR	NRR	4500		A sample was removed and broken into 4 pieces; equated to Pu and Sr-Y
				4600	1300	NRR	NRR	4500		
				600	900	NRR	NRR	4500		
				1900	1100	NRR	NRR	4500		

FOOTNOTES FOR TABLE 1

^aThe beta mode direct readings and alpha mode direct readings are taken with PAC instruments (see Appendix 1). The beta mode detects both electromagnetic and particulate radiation. If an area indicated an instrument reading higher than background, a beta mode reading was obtained. The instrument was then switched to the alpha mode, and a reading of the alpha contamination was obtained. In the alpha mode, the instrument only responds to particles with high specific ionization, such as alpha particles. The beta mode readings were compensated for any alpha contribution by subtracting the alpha mode reading.

^bNS = Not Selected, indicating that the room or area was not selected for an air sample. Air samples were collected at locations where soil was exposed as a result of the excavation.

^cBKGD = Background. The following are the instrument background readings:

	<u>Beta Mode</u>	<u>Alpha Mode</u>
PAC-4G-3	200-400 cts/min-100 cm ²	0-5 cts/min-100 cm ²
PRM-5-3	1.0-3.0 x 10 ³ cts/min	
GM End Window Detector read < 0.03 mR/h at contact		
μR/h meter reading at 1 m above floor 4-15 μR/h.		

^dNA = Non-Applicable. No contamination was detected above background in the beta mode; therefore, no alpha mode or contact GM End Window survey was necessary.

^eα = Alpha; βγ = Beta-Gamma (The beta-gamma readings are compensated for any alpha contamination by subtracting the alpha reading.)

^fNRR = No Reading Recorded.

TABLE 2

RADON DETERMINATIONS

Location	Figure	ANL METHOD				SCINTILLATION CELLS	
		Air Sample Number	Alpha dis/min-m ³ (100-min)	pCi/l $\pm \sigma^a$ (²²² Rn)	WL ^b	pCi/l (²²⁰ Rn)	Air Sample Number pCi/l $\pm \sigma^a$ (²²² Rn)
Room 1	3	1	7.1	0.029 \pm 0.025	2.9x10 ⁻⁴	0.0038 \pm 0.0021	4 0.06 \pm 0.05 ^c
Room 2	3	2	8.5	0.075 \pm 0.023	7.5x10 ⁻⁴	0	3 0.13 \pm 0.06
Basement Hall	3						5 0.22 \pm 0.07
Attic	6						6 0.07 \pm 0.03
Outdoors	15						7 0.02 \pm 0.03

^a One standard deviation due to counting statistics.

^b A Working Level (WL) is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon daughter products RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of ²²²Rn per liter of air.

^c No correction has been made for the thoron (²²⁰Rn) detected in the ANL method.

TABLE 3

SAMPLE WEIGHTS
(grams)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
SOIL				
KC-S4	3393	3113	2149	955
KC-S5	3185	2741	2146	589
KC-S6	3207	2738	1557	1177
KC-S7	3562	3235	2015	1218
KC-S8	1404	1262	820	440
KC-S9	3743	3383	1849	1530
SEWER SLUDGE				
KC-SS10	1296	929	429	484
KC-SS11	2020	1530	1389	134
KC-SS12	1706	1448	594	846
KC-SS13	1771	1509	513	993
CLAY PIPE				
KC-PIPE-14	550	-	-	-

TABLE 4

GAMMA SPECTRAL AND URANIUM FLUOROMETRIC
ANALYSES OF SAMPLES

Sample No.	Gamma Spectra, pCi/g $\pm\sigma^a$				Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain		$\mu\text{g/g} \pm 10\%$	pCi/g $\pm 10\%^b$
SOIL						
KC-S4	<0.03	0.21 \pm 0.06	0.31 \pm 0.03		1.4 \pm 0.14	0.96 \pm 0.096
KC-S5*	<0.03	0.19 \pm 0.06	0.65 \pm 0.07		35.0 \pm 3.50	23.9 \pm 2.39
KC-S6*	<0.03	0.24 \pm 0.07	3.76 \pm 0.38		8.0 \pm 0.80	5.5 \pm 0.55
KC-S7*	<0.03	0.53 \pm 0.06	4.47 \pm 0.45		33.0 \pm 3.30	22.5 \pm 2.25
KC-S8*	<0.03	0.51 \pm 0.06	16.00 \pm 2.00		19.0 \pm 1.90	13.0 \pm 1.30
KC-S9*	<0.03	0.04 \pm 0.02	13.00 \pm 1.00		23.0 \pm 2.30	15.7 \pm 1.57
SEWER SLUDGE						
KC-SS10	0.81 \pm 0.08	0.66 \pm 0.07	9.50 \pm 1.00		160.0 \pm 16.00	109.3 \pm 10.93
KC-SS11	0.06 \pm 0.02	0.06 \pm 0.03	0.47 \pm 0.05		1.8 \pm 0.18	1.2 \pm 0.12
KC-SS12	0.30 \pm 0.04	0.60 \pm 0.06	9.30 \pm 1.00		21.0 \pm 2.10	14.3 \pm 1.43
KC-SS13	0.50 \pm 0.05	2.20 \pm 0.22	10.00 \pm 1.00		54.0 \pm 5.40	36.9 \pm 3.69
CLAY VENTILATION PIPE						
KC-Pipe-14					<u>$\mu\text{g Total}$</u>	<u>pCi Total^b</u>
Contami- nated	0.05 \pm 0.03	0.5 \pm 0.3	0.9 \pm 0.4			
Control ^c	0.1 \pm 0.05	1.1 \pm 0.5	0.8 \pm 0.4			
Etch Solution ^d					16	11

^a One standard deviation due to counting statistics.

^b ANL conversion from Appendix 5.

^c Control sample (27.3 g) was chiseled from the unetched side of ventilation pipe.

^d Sample KC-PIPE-14, tile, was treated with 8M HNO₃ on its inside surface to remove uranium by dissolution.

Comments

The ventilation pipe was broken into four pieces so that counting could be done at meaningful geometries. Conclusions are that some of the activity was dissolved during the chemical etch; however, the bulk of the activity still remains embedded in the tile matrix.

*Areas subsequently cleaned to levels below detectable limits with portable survey instruments during post remedial action survey activities.

TABLE 5

BACKGROUND SOIL SAMPLE DATA^a
Cesium-137, Thorium-232, and
Natural Uranium in Soil, 1979

(Concentrations in pCi/g)

Date Collected	Location	Cesium-137	Thorium-228	Radium-226	Uranium (natural)
June 6	Argonne Area ^b	0.6±0.1	0.9±0.1	1.2±0.1	1.4±0.1
June 6	Argonne Area	0.5±0.1	0.9±0.2	1.8±0.2	1.4±0.2
June 6	Argonne Area	2.1±0.1	0.8±0.1	1.2±0.1	1.8±0.2
June 6	Argonne Area	1.3±0.1	0.9±0.1	1.1±0.1	1.6±0.2
June 6	Argonne Area	0.8±0.1	0.8±0.1	1.1±0.1	1.3±0.1
December 10	Argonne Area	0.1±0.1	0.6±0.1	1.0±0.1	1.6±0.1
December 10	Argonne Area	0.4±0.1	0.7±0.1	1.0±0.1	1.5±0.1
December 10	Argonne Area	1.1±0.1	0.7±0.1	1.1±0.1	1.2±0.1
December 10	Argonne Area	1.3±0.1	0.9±0.1	0.8±0.1	1.1±0.1
December 10	Argonne Area	1.1±0.1	0.8±0.1	0.9±0.1	0.9±0.1
	Average	0.9±0.4	0.8±0.1	1.1±0.2	1.4±0.2
June 5	Channahon, IL	0.8±0.1	0.8±0.1	0.9±0.1	1.1±0.1
June 5	Starved Rock State Park, IL	0.7±0.1	0.4±0.1	0.7±0.1	0.8±0.1
June 5	Morris, IL	2.8±0.1	0.6±0.1	2.3±0.1	3.8±0.5
June 12	Downers Grove, IL	0.5±0.1	1.0±0.1	1.2±0.1	1.0±0.4
June 12	Western Springs, IL	0.8±0.1	0.9±0.1	1.7±0.1	1.9±0.2
June 12	Brookfield, IL	1.3±0.1	0.9±0.1	1.3±0.1	1.6±0.2
October 4	Willow Springs, IL	0.9±0.1	0.8±0.1	1.2±0.1	0.9±0.1
October 4	Woodridge, IL	1.1±0.1	0.8±0.1	1.2±0.1	1.3±0.1
October 9	McKinley Woods State Park, IL	1.0±0.1	0.8±0.1	1.0±0.1	1.3±0.1
October 9	Dresden Lock and Dam, IL	0.4±0.1	0.7±0.1	1.2±0.1	1.4±0.1
	Average	1.0±0.4	0.8±0.1	1.3±0.3	1.5±0.6

^aThese results are transcribed from "Environmental Monitoring at Argonne National Laboratory: Annual Report for 1979" (ANL-80-29) by N. W. Golchert, T. L. Duffy, and J. Sedlet.

^bAll sites marked "Argonne Area" were within the boundaries of Argonne National Laboratory near Lemont, Illinois, southwest of Chicago.

TABLE 6

GAMMA-RAY SPECTRAL AND URANIUM-FLUOROMETRIC
ANALYSES OF SOIL SAMPLES

Sample Number	Gamma Spectra pCi/g $\pm\sigma^a$				
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	Uranium Fluorometric $\mu\text{g/g}\pm 10\%^b$	pCi/g $\pm 10\%^c$
KC-1A	0.82 \pm 0.05	0.9 \pm 0.1	0.85 \pm 0.08	4.9 \pm 0.4	3.3 \pm 0.3
KC-1B				2.4 \pm 0.3	1.6 \pm 0.2
KC-1C				3.2 \pm 0.4	2.2 \pm 0.3
KC-1D				1.0 \pm 0.5	0.7 \pm 0.3
KC-2A	0.82 \pm 0.06	0.7 \pm 0.2	1.00 \pm 0.09	5.0 \pm 0.6	3.4 \pm 0.4
KC-2B				2.6 \pm 0.3	1.8 \pm 0.2
KC-2C				3.8 \pm 0.5	2.6 \pm 0.3
KC-2D				2.6 \pm 0.4	1.8 \pm 0.3
KC-3A	1.45 \pm 0.07	0.6 \pm 0.1	0.80 \pm 0.07	2.1 \pm 0.4	1.4 \pm 0.3
KC-3B				1.5 \pm 0.4	1.0 \pm 0.3
KC-3C				2.6 \pm 0.4	1.8 \pm 0.3
KC-3D				1.0 \pm 0.3	0.7 \pm 0.3
LFE Blank	0.00 \pm 0.04	0.0 \pm 0.1	0.00 \pm 0.06	0.0 \pm 0.2	0.0 \pm 0.1

^aOne standard deviation due to counting statistics

^bData results from LFE Corporation Environmental Analysis Laboratories.

^cANL conversion from Appendix 5.

TABLE 7

URANIUM MASS SPECTROSCOPIC ANALYSIS

Sample No.	Atom % U				
	233	234	235	236	238
KC-S5	< 0.0005	0.0056 ± 0.0005	0.7345 ± 0.0020	0.0008 ± 0.0005	99.259 ± 0.003
KC-SS10	< 0.0005	0.0051 ± 0.0005	0.7211 ± 0.0020	<0.0005	99.274 ± 0.003

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY METERS

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was the primary instrument used for surveying. This instrument is a gas-flow proportional counter which utilizes a propane gas-proportional detector, 51 cm² (AC-21), 100 cm² or 325 cm² (AC-22) in area, with a thin double-aluminized Mylar window (~ 0.85 mg/cm²).

Since this instrument has multiple high-voltage settings, it can be used to distinguish between alpha and beta-gamma contamination. This instrument was initially used in the beta mode. In that mode, the detector responds to alpha and beta particles and x- and gamma-rays. When areas indicated a higher count rate than the average instrument background, the beta-mode reading was recorded, and the instrument was then switched to the alpha mode to determine any alpha contribution. In the alpha mode, the instrument responds only to particles with high specific ionization.

The alpha voltage is set to 1600 V, and the input discriminator is set to 1.5 mV. The instrument is then calibrated in the alpha mode with four flat-plate, infinitely thin NBS-traceable ²³⁹Pu standards, and in the beta mode with a flat-plate, infinitely-thin NBS-traceable ⁹⁰Sr-⁹⁰Y standard. The PAC-4G-3 instruments are calibrated to an apparent 50% detection efficiency.

B. Beta-Gamma End Window Survey Meter

When an area of contamination was found with a PAC instrument, a reading was taken with an Eberline Beta-gamma Geiger-Mueller Counter, Model E-530, with a HP-190 probe. This probe has a thin mica end window and is, therefore, sensitive to alpha and beta particles and x- and gamma-rays. A thin piece of aluminum is added to the mica, making the window density approximately 7 mg/cm². At this density, the instrument is not sensitive to the majority of alpha emissions. A maximum reading is obtained with the probe placed in contact with the area of contamination. In this position, the response (in mR/h) to gamma radiation is generally conservative relative to a determination of mrad/h at 1 cm. This instrument is calibrated in mR/h with a ²²⁶Ra standard source.

C. Low-Energy Gamma Scintillation Survey Meter

An Eberline Model PRM-5-3 with a PG-2 gamma scintillation detector was used to determine low-energy x and gamma radiation. The PG-2 detector consists of a thin NaI(Tl) scintillation crystal 5 cm (2 in.) in diameter by 2 mm thick. This instrument is calibrated on three separate discriminators for three energy regions using ²³⁹Pu (17 keV), ²⁴¹Am (59.5 keV) and ²³⁵U (185.7 keV) sources. This instrument can be operated in either a differential (to discriminate between different energy regions) or integral mode.

APPENDIX 1
(cont'd.)

D. High-Energy Micro "R" Scintillation Survey Meter

An Eberline Micro "R" meter model PRM-7 was used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tl) scintillation crystal 2.5 cm (1 in.) in diameter by 2.5 cm (1 in.) thick and can be used to measure fields of low-level radiation between 10 μ R/h and 5000 μ R/h. This instrument is used to survey ambient background radiation. It is held 1 m from the surface during the survey. This instrument is also calibrated with a standard ^{226}Ra source.

E. Pressurized Ion Chamber

In addition to the PRM-7, a pressurized ion chamber (Reuter Stokes Model RSS-111) was used at selected locations to determine the ambient radiation field. The RSS-111 has three output modes: (1) instantaneous exposure rate, (2) strip chart differential readout, and (3) integrated exposure. The chamber is mounted on a tripod, 3 ft (~ 1 m) above the surface and has a uniform energy response from about 0.2 MeV to about 4 MeV. A 3-h period of operation is usually sufficient to obtain significant data.

II. SMEAR-COUNTING INSTRUMENTATION

An ANL-designed gas-flow proportional detector connected to an Eberline Mini Scaler Model MS-2 was used to count multiple smears simultaneously. This detector has a double-aluminized Mylar window (400 cm²) and uses P-10 (90% argon and 10% methane) as the counting gas. The metal sample holder for this detector has been machined to hold ten smear papers. This particular system consists of two Mini Scalers and two detectors. One is used to count in the alpha mode; the other is used in the beta mode. Up to ten samples can be counted simultaneously.

Any smear taken from a contaminated area was counted individually in a Nuclear Measurements Corporation gas-flow proportional counter (PC-5 or PC-3A). These instruments have been modified to contain a double-aluminized Mylar spun top (window). This top is placed over non-conducting media (e.g. paper smears) to negate the dielectric effect on the counter. This counter also uses P-10 counting gas. Smears are counted in both the alpha and beta modes.

The PC counters are calibrated by adjusting the input discriminator with the high voltage set at 700 V until it begins to count an alpha source. The plateaus are run to establish the operating voltages for alpha and beta-gamma. The MS-2 input discriminator is set to 2 mV and again plateaus are run to establish the operating voltages.

III. AIR-SAMPLING DEVICES

Air samples were collected using a commercially available (ANL-modified Filter Queen) vacuum cleaner identified as the "Princess Model." Air was drawn through a filter medium at a flow rate of 40 m³/h. The filters consist of 200-cm² sheets of Hollingsworth-Vose (HV-70) or LB5211-9 mil filter paper. The collection efficiency at these flow rates for 0.3- μ m particles is about 99.9%.

APPENDIX 1
(cont'd.)

A separate air sample can be taken with a positive displacement pump drawing about 20 liters/min through a Millipore membrane (0.5 to 0.8 μ m) filter paper for about one hour. An alpha spectrum can be measured from a section of this filter paper. The ratio of actinon (^{219}Rn - 6.62 MeV α AcC) to radon (^{222}Rn - 7.69 MeV RaC') can be determined from this spectrum.

Ambient radon concentration measurements are also conducted by taking grab samples with detached 0.5- ℓ Eberline scintillation cells. The 0.5- ℓ cells are coated on the inside with zinc sulfide. The top and sides are wrapped with white paper and black electrical tape. After a suitable time to allow the radon daughters to equilibrate (3-4 hours) the cells are counted with an Eberline SAC-R5 photomultiplier counting system for 30 or 60 minutes.

For calibration, ten cells were loaded with radon gas generated by the radon bubbler system and were counted with Eberline SAC-R5 photomultiplier counting systems. The SAC-R5 systems were set up for discrimination of a 10-mV pulse at a threshold setting of 1.0. Calibrations were done for both evacuated and flow-through loading techniques, and resulted in a calibration factor (Y) of 2.25 cts/min-pCi/ ℓ for each technique. The scintillation cells were loaded with nitrogen to obtain an average cell background of 0.20 cts/min. The lower detection limit was then determined to be 0.12 ± 0.04 pCi/ ℓ radon-222 for a 60-minute counting interval. The radon concentration is:

$$C = \frac{A - A_0}{Y}$$

where: A = count rate of sample
 A_0 = background count rate (0.2 cts/min).

IV. GAMMA SPECTRAL INSTRUMENTATION

A Nuclear Data Multichannel Analyzer Model ND-100, utilizing a 7.6-cm (3 in.) diameter by 7.6-cm (3 in.) thick NaI(Tl) scintillation crystal is commonly used for determining a gamma spectrum. This instrument is calibrated with NBS-traceable gamma sources. Samples from contaminated areas were analyzed using this system, and the contamination radionuclides were identified.

Hyperpure Germanium detectors (ORTEC - 17% efficiency right-circular cylinders) can be used when more sophisticated gamma-ray analyses are required. These detectors are coupled to Nuclear Data Multichannel Analyzers (Models ND-60, ND-66 or ND-100).

APPENDIX 2

CONVERSION FACTORS

I. INSTRUMENTATION

The factors used to convert the instrument readings to units of disintegrations per minute per 100 cm² (dis/min-100 cm²) and the derivation of those factors are listed below.

A. Conversion Factors

	<u>PAC-4G-3</u> <u>(51 cm²)</u>		<u>PAC-4G-3</u> <u>(100 cm²)</u>		<u>Floor</u> <u>Monitor (FM-4G)</u>	
	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>
To 100 cm ²	1.96	1.96	1.00	1.00	0.31	0.31
dis/min per cts/min for ⁹⁰ Sr- ⁹⁰ Y	-	2	-	2	-	2
dis/min per cts/min for ²³⁹ Pu	2	-	2	-	2	-
dis/min per cts/min for normal U	3.5	2.7	2.7	2.4	3.0	2.5
dis/min per cts/min for ²²⁶ Ra plus daughters	1.7	1.7	1.7	1.8	1.7	1.8

B. Derivation of Conversion Factors. Floor Monitor

Window Area: ~ 325 cm²

Conversion to 100 cm² = 0.31 times Floor Monitor readings

. PAC-4G-3

Window Area: ~ 51 cm²

Conversion to 100 cm² = 1.96 times PAC reading

Window Area: ~ 100 cm²

Conversion factor = 1.00 times PAC reading.

. 2 π Internal Gas-Flow Counter, PC counter

Geometry: Solid Steel Spun Top - 0.50

APPENDIX 2
(cont'd.)

Geometry: Mylar Spun Top - 0.43

Mylar spun top counting {double-aluminized Mylar window ($\sim 0.85 \text{ mg/cm}^2$)} utilizes the well of the PC counter and is a method developed and used by the Argonne National Laboratory Health Physics Section for negating the dielectric effect in counting samples on nonconducting media.

The PAC-4G-3 and PC counter were calibrated as described in Appendix 1. Using a flat-plate, infinitely thin ^{226}Ra plus short-lived daughters standard as a source of alpha emissions, the plate was counted in a 2π Internal Gas-Flow Counter (PC counter) with the source leveled to an apparent 2π geometry. The alpha counts per minute (cts/min) reading was found to be 1.86×10^4 cts/min, or $1.86 \times 10^4 \div 0.51^* = 3.65 \times 10^4$ disintegrations per minute (dis/min) alpha. Since the source was infinitely-thin, the alpha component was used as the total alpha dis/min of the source.

The same ^{226}Ra plus daughters source, when counted with the PAC instrument in the alpha mode, was found to be 2.18×10^4 cts/min at contact. The conversion factor for cts/min to dis/min for the PAC instrument is $3.65 \times 10^4 \div 2.18 \times 10^4 = 1.7$ dis/min per cts/min alpha.

The same source was covered with two layers of conducting paper, each 6.31 mg/cm^2 , to absorb the alpha emissions. With the PC counter in the beta mode and the paper in good contact with the chamber, the count was found to be 1.17×10^4 cts/min or $1.17 \times 10^4 \div 0.50 = 2.35 \times 10^4$ dis/min beta. With the PAC-4G-3 in the beta mode and in contact with the covered source in the center of the probe, the count was found to be 1.36×10^4 cts/min. This indicates a conversion factor of $2.35 \times 10^4 \div 1.36 \times 10^4 = 1.7$ dis/min per cts/min beta-gamma. All three detectors (51 cm^2 , 100 cm^2 , and 325 cm^2) gave readings similar to those reported above for the alpha and beta-gamma modes.

Utilizing a $1.25 \text{ in} \times 1.25 \text{ in} \times 0.005 \text{ in}$ ($3.2 \text{ cm} \times 3.2 \text{ cm} \times 0.013 \text{ cm}$) normal uranium foil as a source of uranium alpha emissions, the foil was counted in a PC counter with the source leveled to an apparent 2π geometry. The same normal uranium source, covered with two layers of conducting paper in good contact with the chamber, each 6.31 mg/cm^2 to negate the alpha emissions, was counted for composite beta and gamma emissions in the PC counter. The source was leveled to an apparent 2π geometry; however, no provision was made for backscatter.

The normal uranium source was also counted with the PAC instruments using all three detector areas in the alpha mode and covered with two layers of conducting paper in the beta mode. The conversion factors were calculated as for ^{226}Ra .

*The value of 0.51 includes the following factors: geometry (g) = 0.50; backscatter factor (bf) = 1.02; sample absorption factor (sa) = 1.0; window air factor (waf) = 1.0. The product of $g \times bf \times sa \times waf$ is 0.51.

APPENDIX 2
(Cont'd.)

II SMEAR COUNT

The conversion factors for cts/min-100 cm² to dis/min-100 cm² for smear counts are given below:

A. Conversion Equation (Alpha)

$$\frac{\text{cts/min} - (\text{Bkgd})}{g \times \text{bf} \times \text{sa} \times \text{waf}} = \text{dis/min } \alpha$$

A geometry factor (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.0 was used when determining alpha activity on a filter media.

The self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotope were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were not known, the (waf) of ²³⁹Pu (0.713) was used.

The (waf) for alpha from ²²⁶Ra plus daughters is 0.55.

B. Conversion Equation (Beta)

$$\frac{\text{cts/min} - \{\beta \text{ Bkgd (cts/min)} + \alpha \text{ cts/min}\}}{g \times \text{bf} \times \text{sa} \times \text{waf}} = \text{dis/min } \beta$$

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.1 was used when determining beta activity on a filter media.

A self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotopes were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were unknown, the (waf) of ⁹⁰Sr-⁹⁰Y (0.85) was used.

The (waf) for betas from ²²⁶Ra plus daughters is 0.85.

APPENDIX 3

RADON-DETERMINATION CALCULATIONS

Calculations for determining radon concentrations in air samples collected with an Argonne National Laboratory-designed air sampler using HV-70 or LB5211 filter media are summarized in this appendix; the basic assumptions and calculations used to derive the air concentrations also are included.

I. RADON CONCENTRATIONS

The following postulates were assumed in deriving the radon (^{222}Rn) concentrations based on the RaC' alpha count results.

- A. RaA, RaB, RaC, and RaC' are in equilibrium.
- B. RaA is present only in the first count and not the 100-minute decay count.
- C. One-half of the radon progeny is not adhered to airborne particulates (i.e., unattached fraction) and, therefore, is not collected on the filter media.
- D. The geometry factor (g) is 0.43 for both the alpha and beta activity.
- E. The backscatter factor (bf) for alpha activity is 1.0.
- F. The sample absorption factor (sa) for RaC' is 0.77.
- G. The window air factor (waf) for RaC' is 0.8.
- H. RaB and RaC, being beta emitters, are not counted in the alpha mode.
- I. The half-life of the radon progeny is approximately 36 minutes, based on the combined RaB and RaC half-lives.
- J. Thoron and long-lived alpha emitters are accounted for using the 360-minute decay count and the seven-day count, respectively.
- K. For all practical purposes, RaC' decays at the rate of the composite of RaB and RaC, which is about 36 minutes.

The following postulates were assumed in deriving the thoron (^{220}Rn) concentrations.

- L. ThA, ThB, ThC and ThC' are in equilibrium.
- M. ThA and RaC' have decayed by the 360-minute decay count.

APPENDIX 3
(cont'd.)

- N. The geometry factor (g), backscatter factor (bf), sample absorption factor (sa) and window air factor (waf) all are the same for thoron as for radon.
- O. ThB and 64% of ThC, being beta emitters, are not counted in the alpha mode.
- P. The half-life of the thoron progeny is 10.64 hours (638.4 minutes) based on the ThB half-life.
- Q. For all practical purposes, 36% of the ThC (alpha branch) and the ThC' decay at the same rate as ThB, which is 638.4 minutes.
- R. The counter does not differentiate between the ThC alphas and the ThC' alphas.

The following postulates were assumed in deriving the actinon (^{219}Rn) concentrations.

- S. AcA, AcB and AcC are in equilibrium.
- T. AcA has decayed by the 100-minute decay count.
- U. The geometry (g), backscatter (bf), sample absorption (sa) and window air factor (waf) factors all are the same for actinon as for radon.
- V. AcB, being a beta emitter, is not counted in the alpha mode.
- W. The half-life of the actinon progeny is 36.1 minutes based on the AcB half-life.
- X. For all practical purposes, the AcC decays at the same rate as AcB, which is 36.1 minutes.
- Y. 84% of the AcC decays by 6.62 MeV α emissions and 16% decays by 6.28 MeV α emissions.

The following postulate was assumed in deriving the long-lived concentration.

- Z. The long-lived activity, as determined from the seven-day count, is assumed to be constant during the entire counting periods. This assumption is valid for isotopes with half-lives longer than a few years.

APPENDIX 3
(cont'd.)

II. EQUATIONS USED TO DERIVE AIR CONCENTRATIONS

$$A_o = \frac{A}{e^{-\lambda t}}$$

Where: A_o = activity (dis/min) present at the end of the sampling period (usually 40 minutes)

A = activity (dis/min) at some time, t , after end of the sampling period

t = time interval (minutes) from end of sampling period to counting interval (usually ≈ 100 minutes)

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$ = half-life of isotope (min).

Concentration is determined by the equation:

$$C = \frac{A_o \lambda}{f} \times \frac{1}{1 - e^{-\lambda t_s}}$$

Where: C = concentration (dis/min-m³)

A_o = activity on filter media at end of sampling period (dis/min)

f = sampling rate (m³/min = m³/h x 1 h/60 minutes)

t_s = length of sampling time (minutes)

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$ = half-life of isotope or controlling parent (minutes).

III. ACTINON CORRECTION

Since the actinon (²¹⁹Rn) progeny (AcA, AcB & AcC) decays at the AcB half-life of thirty-six minutes, it cannot be distinguished from the radon (²²²Rn) progeny using standard air sampling with HV-70 or LB5211 filter media and standard alpha-counting techniques. A positive displacement pump is used to

APPENDIX 3 (cont'd.)

collect a sample on Millipore membrane (0.5 to 0.8 μ m) filter media. The sample rate is approximately 20 liters/minute for a sampling time of at least 90 minutes. The center portion of the sample is removed and counted in an alpha spectrometer which exhibits the 6.62 MeV AcC alpha emissions and the 7.69 MeV RaC' alpha emissions. If these two peaks are observed in the spectrum, then the following calculations are performed:

$$B_j = \sum_{i=1}^n b_{ij}$$

Where: B_j = summation of the counts in n channels under peak j

b_{ij} = the number of counts in channel i of peak j

j = 1 for the 6.62 MeV peak of actinon; 2 for the 7.69 MeV peak of radon

n = total number of channels in the summation.

The fractions of the activity with a 36-minute half-life due to actinon and radon are then:

$$\text{Actinon} = \frac{B_1/0.84}{B_1/0.84 + B_2}$$

$$\text{Radon} = \frac{B_2}{B_1/0.84 + B_2}$$

where 1 refers to actinon progeny and 2 refers to radon progeny.

IV. EXAMPLE CALCULATION

Data have been created to correspond to values likely to occur if all possible types of contamination are present in the air of a room where a sample is collected. The application of the equations for determining all types of activity and their concentrations are given below.

Data	f = 40 m ³ /60 min	t = 40 min
at t = 100 min		A ^s = 2000 dis/min
at t = 360 min		A = 140 dis/min
at t = 7 days		A = 5 dis/min

APPENDIX 3
(cont'd.)

For long-lived activity:

$$A_o = A = 5 \text{ dis/min}$$

$$C(L) = A_o / fxt_s = \frac{5}{40/60 \times 40} = 0.19 \text{ dis/min-m}^3.$$

For thoron:

$$A_o = \frac{140-5}{\exp - \frac{0.693 \times 360}{638.4}} = 199.6 \text{ dis/min}$$

$$C(Tn) = \frac{199.6 \times \frac{0.693}{638.4}}{40/60} \times \frac{1}{1 - \exp \frac{-0.693 \times 40}{638.4}} = 7.6 \text{ dis/min-m}^3.$$

For radon (^{222}Rn) and actinon (^{219}Rn), activity due to thoron at $t = 100 \text{ min}$:

$$A = \frac{135}{\exp - \frac{0.693 \times 260}{638.4}} = 179 \text{ dis/min.}$$

Activity due to the isotopes with a 36 minute half-life:

$$A = 2000 - 179 - 5 = 1816 \text{ dis/min}$$

$$A_o = \frac{1816}{\exp - \frac{0.693 \times 100}{36}} = 12,454 \text{ dis/min}$$

$$C(36) = \frac{12,454 \times \frac{0.693}{36}}{40/60} \times \frac{1}{1 - \exp \frac{-0.693 \times 40}{36}} = 669.7 \text{ dis/min-m}^3.$$

When an actinon peak is seen at 6.62 MeV, the counts under the two peaks are summed. For example, if 10 channels are summed, the following counts are found:

APPENDIX 3
(cont'd.)

For 6.62 MeV peak: 44 in 10 channels, where the 6.62 alpha emissions are 84% of the total.

For 7.69 MeV peak: 601 counts in 10 channels, where the 7.69 MeV alpha emissions are 100% of the total.

$$B_1 = 44$$

$$B_1/0.84 = 52 \text{ counts}$$

$$B_2 = 601 \text{ counts}$$

$$\text{Actinon} = 52/653 = 0.08$$

$$\text{Radon} = 601/653 = 0.92$$

$$C(\text{Rn}) = C(36) \times \text{Radon}\% = 669.7 \times 0.92 = 616.1 \text{ dis/min-m}^3$$

$$C = C(36) \times \text{Actinon}\% = 669.7 \times 0.08 = 53.6 \text{ dis/min-m}^3.$$

Since we assume that on the average half of the progeny is not adhered to the airborne particulates, the above concentrations are then doubled to determine actual concentrations. We assume that there is no unattached fraction for the long-lived activity.

$$C \text{ actual} = C \text{ measured} \times \text{progeny correction factor}$$

$$C(\text{L}) = 0.19 \text{ dis/min-m}^3$$

$$C(\text{Tn}) = 7.6 \text{ dis/min-m}^3 \times 2 = 15.2 \text{ dis/min-m}^3$$

$$C(\text{An}) = 53.6 \text{ dis/min-m}^3 \times 2 = 107.2 \text{ dis/min-m}^3$$

$$C(\text{Rn}) = 616 \text{ dis/min-m}^3 \times 2 = 1232 \text{ dis/min-m}^3.$$

These would then be the resulting concentrations in dis/min-m^3 . To convert to pCi/ℓ , divide the concentrations by 2.2×10^3 :

$$C(\text{L}) = \frac{0.19 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3/\text{pCi}/\ell} = 8.6 \times 10^{-5} \text{ pCi}/\ell$$

APPENDIX 3
(cont'd.)

$$C(Tn) = \frac{15.2 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3/\text{pCi/l}} = 0.0068 \text{ pCi/l}$$

$$C(An) = \frac{107.2 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3/\text{pCi/l}} = 0.048 \text{ pCi/l}$$

$$C(Rn) = \frac{1232 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3/\text{pCi/l}} = 0.55 \text{ pCi/l.}$$

APPENDIX 4

SAMPLE PREPARATION AND ANALYSIS GENERIC PROTOCOL

I. SOIL-SAMPLE PREPARATION

Soil samples are acquired as previously described. These samples are bagged and identified at the collection site and returned to ANL. If there is an indication of radioactive contamination, the sample is sealed in a Nalgene jar. At ANL, the soil samples are logged into the soil-sample book, and each sample is weighed (on a tared balance scale) and the weight is marked on the container. This weight is recorded in the soil book as a "net weight."

After all samples are marked, weighed, and recorded, they are dried. Each sample is placed in a pyrex beaker marked with the sample identification number. If more than one beaker is necessary, additional numbers (e.g., 1-3, 2-3, 3-3) are used. The original containers are saved for repackaging the dried samples. The beaker is set in an 80°C oven until the soil is dry (approximately 48 hours). The sample is returned to the original container and reweighed using a tared balance scale. This weight is also marked on the container and in the soil-sample book, where it is referred to as a "dry weight."

After all the samples are returned to their original containers, the milling process is started. Each dried sample is transferred to a 2.3-gallon ceramic mill jar containing mill balls (1½" x 1½" burundum cylinders). The mill jar number is marked on the original container. The jars are sealed and the samples are milled for two hours or until sufficient material is produced to obtain 100 g and 5 g samples for analyses. The samples are milled six at a time. A second set of six jars is prepared while the milling of the first set is proceeding. After each sample is milled, the mill balls are removed with tongs and placed in a tray. A large plastic bag is inverted over the mill jar. Both are inverted and shaken until all the soil is transferred to the bag. If the soil plates the inside of the mill jar, a small paint brush is used to loosen the soil before the jar is inverted. A separate brush is used for each jar to prevent cross-contamination of the soil samples.

After milling, each sample is sieved through a number 30 standard testing sieve (600 µ mesh) and transferred to a 12" x 12" ziplock bag. Rocks and dross are bagged separately. The bags are marked with the sample number, the sieve number and R(rocks) or S(soil). The balance is tared and the weights of the soil (or rocks) are measured and recorded in the soil-sample book. A 100-g sample of the sieved material is transferred to a 4-oz. Nalgene bottle. These samples are analyzed by suitable analytical techniques, including, as a minimum, gamma spectroscopy (GeLi). A 5-g sample of the sieved material is transferred to a 1-oz Nalgene bottle. One gram of this sample is used for the determination of uranium by laser fluorometry; 100 grams are needed for radiochemical analysis for Pu, Am and Th if these analyses are required. The bottles containing these weighed samples are marked with sample number and date, and this information is recorded in the soil-sample book. The rocks (and dross) and remaining soil are placed in storage.

APPENDIX 4 (cont'd.)

The sieves, mill jars, and burundum milling balls used in this work are classified in two sets. One set is used for background samples exclusively. The other set is used for all samples from suspect areas. Soil samples with elevated levels of radioactivity based on instrument measurements are milled in one-gallon Nalgene bottles using burundum balls from the set used for suspect samples. After use, these balls are either decontaminated (see below) or disposed of as radioactive waste. The Nalgene bottles are always disposed of as radioactive waste. The sieves used for these samples are also from the set used for suspect samples and are decontaminated after use.

II. EQUIPMENT DECONTAMINATION

The care of the milling apparatus is as important as the actual sample preparation. Proper care prevents cross-contamination of successive samples. The beakers used to dry the samples are washed thoroughly by placing a small amount of Haemo-Sol in each beaker and filling with warm water. The beaker is then scrubbed thoroughly on the inside and scoured on the outside with scouring powder. The beakers are rinsed three times with tap water and three times with demineralized water, and finally dried thoroughly before reuse.

The milling apparatus (tongs, brushes, milling jars, lids, and milling balls) are rinsed. The tongs and brushes are washed thoroughly with Haemo-Sol. Eight burundum balls are returned to each milling jar along with about one pint of clean road gravel, one spoon of Haemo-Sol, one spoon of scouring powder with bleach, and one quart of water. The lid is tightened on the jar and the jar is placed on the rolling mill and rolled for approximately two hours or until the balls and the inside of the jar appear to be physically clean. After this time, the mill jar is removed from the rolling mill and its contents are dumped into a screen or basket. The lid and balls are then rinsed thoroughly three times with tap water followed by three times with demineralized water. The inside of the jar is rinsed until it is absolutely clean. The milling apparatus is air-dried with warm air. Room air is drawn through the mill jars with a hose which is attached to a fume hood or specially constructed drying box.

The sieves are rinsed, washed in Haemo-Sol, thoroughly rinsed (three times with tap water, followed by three times with demineralized water) and then air dried as above before reuse.

III. WATER AND SLUDGE

Water samples are collected in 0.1-liter, 0.5-liter and/or 1-liter quantities as deemed appropriate. These samples are forwarded directly to a certified radiochemistry laboratory for preparation and analysis. The customary analysis procedure consists of filtration to obtain the suspended solids followed by evaporation to obtain the dissolved solids. Both suspended and dissolved solids are analyzed by appropriate radiochemical analytical techniques.

Sludge samples are collected in 0.1-liter bottles and are processed as outlined above for water samples.

APPENDIX 4
(cont'd.)

IV. VEGETATION, TRASH AND RUBBLE

Samples of potentially contaminated vegetation, trash (e.g. piping, ducts, conduit, etc.) and rubble are collected, bagged, and labeled at the site and returned to ANL for analysis.

Vegetation samples are initially weighed and transferred to Marinelli beakers for gamma spectrometric analysis. Then they are ashed, reweighed, and analyzed by appropriate analytical techniques.

Trash and rubble samples are forwarded to a certified radiochemistry laboratory for analysis.

V. TRITIUM FROM SOLID MATERIALS

Samples of solid materials (e.g., concrete) suspected of containing tritium are collected, broken into small pieces, and submitted to a certified radiochemistry laboratory for analysis. The standard analytical procedure consists of transferring a 20-40 g sample to a ceramic boat followed by heating in a tube furnace at 425°C for a period of two hours (~ 40 min to reach temperature and ~ 80 min heating at temperature). Helium is used as a flow gas through the tube during heating, and the tritium is collected in two traps on the downstream side of the furnace. The first trap is immersed in an ordinary ice bath (0°C); the second trap is immersed in a CO₂-Freon bath (-57°C). The collected tritiated water from both traps is combined, made up to a known volume, and an aliquot taken for liquid scintillation counting of the tritium.

VI. ANALYSIS PROCEDURES

A 100-g or less fraction from each soil sample is analyzed by high resolution gamma-ray spectroscopy using a germanium crystal detector coupled to the appropriate electronics and a multichannel analyzer. This analysis allows for a quantitative determination of the ²²⁶Ra decay chain (via the 609 keV γ-ray of ²¹⁴Pb) and the ²³²Th decay chain (via the 911 keV γ-ray of ²²⁸Ac), as well as any other gamma emitting radionuclide, (e.g., ¹³⁷Cs) present in the soil.

The total uranium (elemental) present in the soil is determined by an acid leach of the soil sample followed by laser fluorometry of the leached sample.

Thorium analysis consists of an acid leach of the soil or other sample (using a ²³⁴Th spike for yield determination) followed by plating a thin source of the radiochemically separated thorium and determining the thorium isotopes (²²⁸Th and ²³²Th) by alpha spectroscopy.

Plutonium and/or americium analysis consists of an acid leach of the soil or other sample (using an appropriate spike for yield determination) followed by plating a thin source of the radiochemically separated plutonium or americium and determining the activity of the isotopes (²³⁸Pu, ^{239,240}Pu or ²⁴¹Am) by alpha spectrometry.

APPENDIX 4
(cont'd.)

The results of the above measurements allow for quantitative determination of the relative amounts of normal uranium, natural uranium, tailings (i.e., ^{226}Ra decay chain), thorium (^{232}Th), mesothorium (^{228}Ra decay chain), radiothorium (^{228}Th decay chain), plutonium (^{238}Pu , 239 , ^{240}Pu) and americium (^{241}Am) present in the contaminated material.

A mass spectrometric analysis of the uranium fraction is conducted when it is known or is surmised that depleted or enriched uranium might be present.

APPENDIX 5

CALCULATION OF NORMAL-URANIUM SPECIFIC ACTIVITY

The specific activity for normal uranium was obtained by summing the measured specific activities for the individual isotopes weighted according to their normal abundances. Best values for these specific activities of ^{235}U and ^{238}U were taken from A. H. Jaffey et al., Phys. Rev. C 4 1889 (1971). The half-life for each isotope was taken from David C. Kocher, "Radioactive Decay Data Tables - A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments" (1981). The percent abundances were taken from N. E. Holden, BNL-NCS-50605 (1977). Atomic weights were taken from the "Handbook of Chemistry and Physics," 52nd Edition (1971). The specific activity of ^{234}U was calculated from the half-life.

Isotope	Specific Activity	Half-life (years)	Abundance (atom %)	Atomic Weight (grams)	Abundance (wt %)
^{234}U	1.387×10^4 dis/min- μg	2.445×10^5	0.0054	234.0409	0.0053
^{235}U	4.798 dis/min- μg	7.038×10^8	0.720	235.0439	0.7110
^{238}U	0.746 dis/min- μg	4.4683×10^9	<u>99.2746</u>	238.0508	<u>99.2837</u>
			100.0000		100.0000

where $(\text{wt } \%)_i =$

$$\frac{(\text{atom } \%)_i (\text{atomic weight})_i}{\sum_j (\text{atom } \%)_j (\text{atomic weight})_j} = \frac{(\text{atom } \%)_i (\text{atomic weight})_i}{238.0289}$$

Specific activity for normal uranium:

$$\begin{aligned} 0.746 \times 0.99284 \times 2 &= 1.481 \quad \text{dis/min-}\mu\text{g from } ^{234}\text{U} \text{ \& } ^{238}\text{U} \\ 4.798 \times 0.00711 &= 0.034 \quad \text{dis/min-}\mu\text{g from } ^{235}\text{U} \\ &1.515 \quad \text{dis/min-}\mu\text{g for normal U} \end{aligned}$$

or $(1.515 \text{ dis/min-}\mu\text{g}) / (2.22 \text{ dis/min-pCi}) = 0.683 \text{ pCi}/\mu\text{g}$

where ^{234}U is assumed to be in secular equilibrium with the ^{238}U parent.

Note that 2.25% of the total activity is due to ^{235}U and 48.87% each is due to ^{234}U and ^{238}U .

APPENDIX 6

PERTINENT RADIOLOGICAL REGULATIONS,
STANDARDS, AND GUIDELINES

Excerpts From

I. DRAFT AMERICAN NATIONAL STANDARD

N13.12

Control of Radioactive Surface Contamination
on Materials, Equipment, and Facilities to be
Released for Uncontrolled Use

Where potentially contaminated surfaces are not accessible for measurement (as in some pipes, drains, and ductwork), such property shall not be released pursuant to this standard, but shall be made the subject of case-by-case evaluation.

Property shall not be released for uncontrolled use unless measurements show the total and removable contamination levels to be no greater than the values in Table 1 or Table 2. (The values in Table 2 are easier to apply when the contaminants cannot be individually identified.)

Coatings used to cover the contamination shall not be considered a solution to the contamination problem. That is, the monitoring techniques shall be sufficient to determine, and such determination shall be made, that the total amount of contamination present on and under any coating does not exceed the Table 1 or Table 2 values before release.

SURFACE CONTAMINATION LIMITS*

Contaminants			Limit (Activity) + (dis/min-100 cm ²)	Total (Fixed plus Removable)
Group	Description	Nuclides (Note 1)	Removable	
1	Nuclides for which the non-occupational MPC (Note 2) is 2×10^{-13} Ci/m ³ or less or for which the nonoccupational MPC (Note 4) is 2×10^{-7} Ci/m ³ or less	²²⁷ Ac ²⁴¹ , ^{242m} , ²⁴³ Am ²⁴⁹ , ²⁵⁰ , ²⁵¹ , ²⁵² Cf ²⁴³ , ²⁴⁴ , ²⁴⁵ , ²⁴⁶ , ²⁴⁷ , ²⁴⁸ Cm ¹²⁵ , ¹²⁹ I ²³⁷ Np ²³¹ Pa ²¹⁰ Pb ²³⁸ , ²³⁹ , ²⁴⁰ , ²⁴² , ²⁴⁴ Pu ²²⁶ , ²²⁸ Ra ²²⁸ , ²³⁰ Th	20	Nondetectable (Note 3)
2	Those nuclides not in Group 1 for which the nonoccupational MPC (Note 2) is 1×10^{-12} Ci/m ³ or less or for which the nonoccupational MPC (Note 4) is 1×10^{-6} Ci/m ³ or less	²⁵⁴ Es ²⁵⁶ Fm ¹²⁶ , ¹³¹ , ¹³³ I ²¹⁰ Po ²²³ Ra ⁹⁰ Sr ²³² Th ²³² U	200	2000 α Nondetectable β, γ (Note 5)
3	Those nuclides not in Group 1 or Group 2		1000	5000

APPENDIX 6
(Cont'd.)

SURFACE CONTAMINATION LIMITS

* The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm² is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm², if (1) from measurements of a representative number n of sections it is determined that $1/n \sum_{i=1}^n S_i \geq L$, where S_i is the dis/min-100 cm² determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm² exceeds 3 L.

+ Disintegrations per minute per square decimeter.

NOTES:

- (1) Values presented here are obtained from the Code of Federal Regulations, Title 10, Part 20, April 30, 1975. The most limiting of all given MPC values (for example, soluble versus insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fraction shall be less than 1.
- (2) Maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the Nuclear Regulatory Commission (NRC). From the Code of Federal Regulations, Title 10, Part 20, Appendix B, Table 2, Column 1.
- (3) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm².
- (4) Maximum permissible concentration in water applicable to members of the public.
- (5) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey for unconditional release should be performed in areas where the background is ≤ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

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(Cont'd.)

TABLE 2
ALTERNATE SURFACE CONTAMINATION LIMITS

(All Alpha Emitters, except U_{nat} and Th_{nat} , Considered as a Group)*

Contamination Contingencies	Limit (Activity) (dis/min-100 cm ²) ⁺	
	Removable	Total (Fixed Plus Removable)
If the contaminant cannot be identified; or if alpha emitters other than U_{nat} (Note 1) and Th_{nat} are present; or if the beta emitters $_{nat}$ comprise ^{227}Ac or ^{228}Ra .	20	Nondetectable (Note 2)
If it is known that all alpha emitters are generated from U_{nat} (Note 1) and Th_{nat} ; and if beta emitters are present that, while not identified, do not include ^{227}Ac , ^{125}I , ^{226}Ra , and ^{228}Ra .	200	2000 α Nondetectable β, γ (Note 3)
If it is known that alpha emitters are generated only from U_{nat} (Note 1) and Th_{nat} in equilibrium with its decay products; and if the beta emitters, while not identified, do not include ^{227}Ac , ^{125}I , ^{129}I , ^{90}Sr , ^{223}Ra , ^{228}Ra , ^{126}I , ^{131}I and ^{133}I .	1000	5000

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(Cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

* The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm² is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm², if (1) from measurements of a representative number n of sections it is determined that $1/n \sum_{i=1}^n S_i \geq L$, where S_i is the dis/min-100 cm² determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm² exceeds 3 L.

⁺ Disintegrations per minute per square decimeter.

NOTES:

- (1) U_{nat} and decay products.
- (2) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm².
- (3) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey of unconditional release should be performed in areas where the background is ≤ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

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(Cont'd.)

II.

U.S. NUCLEAR REGULATORY COMMISSION
DIVISION OF FUEL CYCLE AND MATERIAL SAFETY
WASHINGTON, D.C.
July 1982GUIDELINES FOR DECONTAMINATION OF FACILITIES
AND EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED
USE OR TERMINATION OF LICENSES FOR BY-PRODUCT
SOURCE, OR SPECIAL NUCLEAR MATERIAL(These have been retyped for
purposes of this report)

The instructions in this guide, in conjunction with Table 1, specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.
2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table 1 prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.
3. The radioactivity on the interior surfaces of pipes, drain lines, or duct work shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or duct work. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.
4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:

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(cont'd.)

- a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.
 - b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.
5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table 1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:
- a. Identify the premises.
 - b. Show that reasonable effort has been made to eliminate residual contamination.
 - c. Describe the scope of the survey and general procedures followed.
 - d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

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(Cont'd.)

TABLE 3

ACCEPTABLE SURFACE CONTAMINATION LIMITS

NUCLIDES ^a	AVERAGE ^{bcf}	MAXIMUM ^{bdf}	REMOVABLE ^{bef}
U-nat, ²³⁵ U, ²³⁸ U and associated decay products	5000 dis/min-100 cm ² α	15,000 dis/min-100 cm ² α	1000 dis/min-100 cm ² α
Transuranics, ²²⁶ Ra, ²²⁸ Ra, ²³⁰ Th, ²²⁸ Th, ²³¹ Pa, ²²⁷ Ac, ¹²⁵ I, ¹²⁹ I	100 dis/min-100 cm ²	300 dis/min-100 cm ²	20 dis/min-100 cm ²
Th-nat, ²³² Th ⁹⁰ Sr, ²²³ Ra, ²²⁴ Ra, ²³² U, ¹²⁶ I, ¹³¹ I, ¹³³ I	1000 dis/min-100 cm ²	3,000 dis/min-100 cm ²	200 dis/min-100 cm ²
Beta-gamma emitters (nu- clides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰ Sr and others noted above.	5000 dis/min-100 cm ² βγ	15,000 dis/min-100 cm ² βγ	1000 dis/min-100 cm ² βγ

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(Cont'd.)

TABLE 3

ACCEPTABLE SURFACE CONTAMINATION LEVELS

- ^aWhere surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.
- ^bAs used in this table, dis/min (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.
- ^cMeasurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.
- ^dThe maximum contamination level applies to an area of not more than 100 cm².
- ^eThe amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.
- ^fThe average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

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III

SURGEON GENERAL'S GUIDELINES
as included in 10 CFR Part 712
Grand Junction Remedial Action Criteria

712.1 Purpose

(a) determination by DOE of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colorado, to radiation emanating from uranium mill tailings which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Pub. L. 92-314 (86 Stat. 222) of June 16, 1972.

712.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colorado, under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of Energy Research and Development or his duly authorized representative.

(b) "Area of Grand Junction, Colorado," means Mesa County, Colorado.

(c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(d) "DOE" means the U.S. Department of Energy or any duly authorized representative thereof.

(e) "Construction-related material" means any material used in the construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

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(Cont'd.)

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) averaging the results of six air samples each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen" (mR) means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-214), Radium C (bismuth-214), and Radium C' (polonium-214).

(k) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colorado.

(l) "Surgeon General's Guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium milling operation involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

712.4 Interpretations

Except as specifically authorized by the Administrator in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of DOE other than a written interpretation by the General Counsel will be recognized to be binding upon DOE.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Department of Energy, Washington, D.C. 20545.

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712.6 General radiation exposure level criteria for remedial action.

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommended the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings.

EGR	RDC	Recommendation
Greater than 0.1 mR/h	Greater than 0.05 WL	Remedial action indicated.
From 0.05 to 0.1 mR/h	From 0.01 to 0.05 WL	Remedial action may be suggested.
Less than 0.05 mR/h	Less than 0.01 WL	No remedial action indicated

712.7 Criteria for determination of possible need for remedial action

Once it is determined that a possible need for remedial action exists, the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made if as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where DOE approved data on indoor radon daughter concentration levels are available

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where DOE approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/h or greater above background.

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(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation level is equal to or exceed 0.02 mR/h above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(B) It should be presumed that if the external gamma radiation level is less than 0.001 mR/h above background, the indoor radon daughter concentration level is less than 0.01 WL above background, and no possible need for remedial actions exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/h above background but is less than 0.02 mR/h above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures:

(i) An external gamma radiation level of 0.15 mR/h above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

712.8 Determination of possible need for remedial action where criteria have not been met.

The possible need for remedial action may be determined where the criteria in 712.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

712.9 Factors to be considered in determination of order of priority for remedial action.

In determining the order or priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) Classification of structure. Dwellings and schools shall be considered first.

(b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.

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(cont'd.)

- (c) Order of application. Insofar as feasible remedial action will be taken in the order in which the application is received.
- (d) Magnitude of radiation level. In general, those structures with the highest radiation levels will be given primary consideration.
- (e) Geographical location of structures. A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involve similar remedial efforts.
- (f) Availability of structures. An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.
- (g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action.

- (a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/h above background in the case of dwellings and schools and 0.15 mR/h above background in the case of other structures.
- (b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. DOE shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

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40 CFR Part 192

HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS
FOR URANIUM MILL TAILINGS

(Excerpts have been retyped for purposes of this report)

SUBPART B--Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to land and buildings which are part of any processing site designated by the Secretary of Energy under Pub. L. 95-604, Section 102. Section 101 of Pub. L. 95-604, states that "processing site" means--

(a) any site, including the mill, containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to any Federal agency prior to January 1, 1971, under a contract with any Federal agency, except in the case of a site at or near Slick Rock, Colorado, unless--

(1) such site was owned or controlled as of January 1, 1978, or is thereafter owned or controlled, by an Federal agency, or

(2) a license [issues by the (Nuclear Regulatory) Commission or its predecessor agency under the Atomic Energy Act of 1954 or by a State as permitted under Section 274 of such Act] for the production at such site of any uranium or thorium product derived from ores is in effect on January 1, 1978, or is issued or renewed after such date; and

(b) Any other real property or improvement thereon which--

(1) is in the vicinity of such site, and

(2) is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

192.11 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Act or in Subpart A.

(b) Land means any surface or subsurface land that is not part of a disposal site and is not covered by an occupiable building.

(c) Working Level (WL) means combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

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(d) Soil means all unconsolidated materials normally found on or near the surface of the earth including, but not limited to silts, clays, sands, gravel, and small rocks.

192.12 Standards

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

(a) the concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than---

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface,
and

(2) 15 pCi/g, averaged 15 cm thick layers of soil more than 15 cm below the surface.

(b) in any occupied or habitable building---

(1) the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

(2) the level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

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V.

EXCERPTS FROM LA-UR-79-1865-Rev.,

"Interim Soil Limits for D&D Projects"

Table XXIII. Recommended Soil Limits^{a,b} (in pCi/g)

	Inhalation	Ingestion		External Radiation	All Pathways ^c
		Home Gardener	Full Diet		
²³¹ Pa	50	740	150	250	40
²²⁷ Ac	200 ^d	4,900	1,000	300	120 ^d
²³² Th	45	670	140	40	20
²²⁸ Th	1,000	37,000	7,800	55	50
²³⁰ Th (No Daught.)	300	4,400	940	36,000	280
²³⁸ U- ²³⁴ U	750	44	8	6,000	40
⁹⁰ Sr	2x10 ⁶	100	19	-	100
¹³⁷ Cs	7x10 ⁶	800	1	90	80

^a Soil limits for ²⁴¹Am and ^{239,240}Pu are available from EPA recommendations, and a soil limit for ²²⁶Ra has been reported by Healy and Rodgers.

^b Limits are to apply to only one nuclide present in the soil. If more than one is present, a weighted average should apply.

^c Based on a diet of a home gardener.

^d Modified from LA-UR-79-1865-Rev. values to correct error.

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VI.

EXCERPTS FROM DOE 5480.1, Chapter XI

"Requirements for Radiation Protection"

Exposure of Individuals and Population Groups in Uncontrolled Areas.
Exposures to members of the public shall be as low as reasonably achievable levels within the standards prescribed below.

Radiation Protection Standards
for Internal and External Exposure
of Members of the Public

Type of Exposure	Annual Dose Equivalent or Dose Commitment	
	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 rem (or 500 mrem)

CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND

Element (atomic number)	Isotope soluble (S) insoluble (I)	Table I Controlled Area		Table II Uncontrolled Area	
		Column 1	Column 2	Column 1	Column 2
		Air (pCi/l)	Water (pCi/l)	Air (pCi/l)	Water (pCi/l)
Radon (86)	Rn 220 S	300		10	
	Rn 222 S	100		3	

APPENDIX 7

EVALUATION OF RADIATION EXPOSURESINTRODUCTIONA. Types of Radiation

Radiation is the emission or transmission of energy in the form of waves or particles. Examples are acoustic waves (i.e., sound), electromagnetic waves (such as radio, light, x- and gamma-rays), and particulate radiations (such as alpha particles, beta particles, neutrons, protons, and other elementary particles).

The class of radiation of importance to this report is known as ionizing radiation. Ionizing radiations are those, either electromagnetic or particulate, with sufficient energy to ionize matter, i.e., to remove or displace electrons from atoms and molecules. The most common types of ionizing radiation are x- and gamma-rays, alpha particles, beta particles, and neutrons.

X- and gamma-rays are electromagnetic waves of pure energy, having no charge and no mass or existence at rest. Gamma-rays and x-rays are identical except that x-rays originate in the atom and gamma-rays originate in the nucleus of an atom. X- and gamma-rays are highly penetrating and can pass through relatively thick materials before interacting. Upon interaction, some or all of the energy is transferred to electrons which, in turn, produce additional ionizations while coming to rest.

Alpha particles are positively charged particulates composed of two neutrons and two protons, identical to the nucleus of a helium atom. Due to its comparatively large mass and double charge, an alpha particle interacts readily with matter and penetrates only a very short distance before coming to rest, causing intense ionization along its path.

Beta particles are negatively charged free electrons moving at high speeds. Due to its comparatively small mass and single charge, a beta particle's penetration through matter is intermediate between that of the alpha particle and the gamma-ray, causing fewer ionizations per unit path length than an alpha particle.

B. Sources of Radiation

Ionizing radiations arise from terrestrial radioactive materials (both naturally occurring and man-made), extra-terrestrial (cosmic) sources, and radiation-producing machines. The sources of ionizing radiation important to this report are radioactive materials and cosmic sources.

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are

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not stable and will spontaneously emit radiation in order to achieve a more stable state. Because of this spontaneous transformation, the ratio of protons and neutrons in the nucleus of an atom is altered toward a more stable condition. Radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma-rays, depending uniquely upon each particular radionuclide. Radionuclides decay at characteristic rates dependent upon the degree of stability and characterized by a period of time called the half-life. In one half-life, the number of radioactive atoms and, therefore, the amount of radiation emitted, decrease by one half.

The exposure of man to terrestrial radiation is due to naturally occurring radionuclides and also to "man-made" or technologically enhanced radioactive materials. Several dozen radionuclides occur naturally, some having half-lives of at least the same order of magnitude as the estimated age of the earth. The majority of these naturally occurring radionuclides are isotopes of the heavy elements and belong to three distinct radioactive series headed by uranium-238, uranium-235, and thorium-232. Each of these decays to stable isotopes of lead (Pb) through a sequence of radionuclides of widely varying half-lives. Other naturally occurring radionuclides, which decay directly to a stable nuclide, are potassium-40 and rubidium-87. It should be noted that even though the isotopic abundance of potassium-40 is less than 0.012%, potassium is so widespread that potassium-40 contributes about one-third of the radiation dose received by man from natural background radiation. A major portion of the exposure (dose) of man from external terrestrial radiation is due to the radionuclides in the soil, primarily potassium-40 and the radioactive decay-chain products of thorium-232 and uranium-238. The naturally occurring radionuclides deposited internally in man through uptake by inhalation/ingestion of air, food, and drinking water containing the natural radioactive material also contribute significantly to his total dose. Many other radionuclides are referred to as "man made" in the sense that they can be produced in large quantities by such means as nuclear reactors, accelerators, or nuclear weapons tests.

The term "cosmic radiation" refers both to the primary energetic particles of extra-terrestrial origin that are incident on the earth's atmosphere and to the secondary particles that are generated by the interaction of these primary particles with the atmosphere, and reach ground level. Primary cosmic radiation consists of "galactic" particles externally incident on the solar system, and "solar" particles emitted by the sun. This radiation is composed primarily of energetic protons and alpha particles. The first generation of secondary particles (secondary cosmic radiation), produced by nuclear interactions of the primary particles with the atmosphere, consists predominantly of neutrons, protons, and pions. Pion decay, in turn, results in the production of electrons, photons, and muons. At the lower elevations, the highly penetrating muons and their associated decay and collision electrons are the dominant components of the cosmic-ray particle flux density. These particles, together with photons from the gamma-emitting, naturally occurring radionuclides in the local environment, form the external penetrating component of the background environmental radiation field which provides a significant portion of the whole-body radiation dose to man.

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In addition to the direct cosmic radiation, cosmic sources include cosmic-ray-produced radioactivity, i.e., cosmogenic radionuclides. The major production of cosmogenic radionuclides is through interaction of the cosmic rays with the atmospheric gases through a variety of spallation or neutron-capture reactions. The four cosmogenic radionuclides that contribute a measurable radiation dose to man are carbon-14, sodium-22, beryllium-7, and tritium (hydrogen-3), all produced in the atmosphere.

BACKGROUND RADIATION DOSES

Background radiation doses are comprised of an external component of radiation impinging on man from outside the body and an internal component due to radioactive materials taken into the body by inhalation or ingestion.

Radiation dose may be expressed in units of rads or rems, depending upon whether the reference is to the energy deposited or to the biological effect. A rad is the amount of radiation that deposits a certain amount of energy in each gram of material. It applies to all radiations and to all materials which absorb that radiation.

Since different types of radiation produce ionizations at different rates as they pass through tissue, differences in damage to tissues (and hence the biological effectiveness of different radiations) has been noticed. A rem is defined as the amount of energy absorbed (in rads) from a given type of radiation multiplied by the factor appropriate for the particular type of radiation in order to approximate the biological damage that it causes relative to a rad of x or gamma radiation. The concept behind the unit "rem" permits evaluation of potential effects from radiation exposure without regard to the type of radiation or its source. One rem received from cosmic radiation results in the same biological effects as one rem from medical x-rays or one rem from the radiations emitted by naturally occurring or man-made radioactive materials.

The external penetrating radiation dose to man derives from both terrestrial radioactivity and cosmic radiation. The terrestrial component is due primarily to the gamma dose from potassium-40 and the radioactive decay products of thorium-232 and uranium-238 in soil as well as from the beta-gamma dose from radon daughters in the atmosphere. Radon is a gaseous member of the uranium-238 chain. The population-weighted external dose to an individual's whole body from terrestrial sources in the United States has been estimated as 15 mrem per year for the Atlantic and Gulf Coastal Plain, 57 mrem per year for an indeterminate area along the Rocky Mountains, and 29 mrem per year for the majority of the rest of the United States. The overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

The cosmic radiation dose, due to the charged particles and neutrons from secondary cosmic rays, is typically about 30% to 50% of the total from all external environmental radiation. The cosmic-ray dose to the population is estimated to be 26 mrem per year for those living at sea level, and increases with increasing altitude. Considering the altitude distribution of the U.S.

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(cont'd.)

population, the population-weighted external cosmic-ray dose is 28 mrem per year. The population-weighted total external dose from terrestrial plus cosmic sources is thus 54 mrem per year for the U.S. population as a whole.

The internal radiation doses derive from terrestrial and cosmogenic radionuclides deposited within the body through uptake by inhalation/ingestion of air, food, and drinking water. Once deposited in the body, many radioactive materials can be incorporated into tissues because the chemical properties of the radioisotopes are identical or similar to stable isotopes in the tissues. Potassium-40, for instance, is incorporated into tissues in the same manner as stable potassium atoms because the chemical properties are identical; radioactive radium and strontium can be incorporated into tissues in the same manner as calcium because their chemical properties are similar. Once deposited in tissue, these radionuclides emit radiation that results in the internal dose to individual organs and/or the whole body as long as it is in the body.

The internal dose to the lung is due primarily to the inhalation of polonium-218 and -214 (radon daughters), lead-212 and bismuth-212 (thoron daughters) and polonium-210 (one of the longer-lived radon decay products). The dose to the lung is about 100 mrem per year from inhaled natural radioactivity. The internal dose from subsequent incorporation of inhaled or ingested radioactivity is due to a beta-gamma dose from incorporation of potassium-40, rubidium-87, and cosmogenic nuclides, and an alpha dose from incorporation of primarily polonium-210, radium-226 and -228, and uranium-238 and -234. The dose to man from internally incorporated radionuclides is about 28 mrem per year to the gonads, about 25 mrem per year to the bone marrow, lung, and other soft tissues, and about 117 mrem per year to the bone (osteocytes). The bone dose arises primarily from the alpha-emitting members of the naturally occurring series, with polonium-210 being the largest contributor. The gonadal and soft tissue doses arise primarily from the beta and gamma emissions from potassium-40. The total internal dose from inhaled plus incorporated radioactivity is about 28 mrem per year to the gonads (or whole-body dose), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body, about 179 mrem per year to the lung, about 79 mrem per year to the bone marrow, and about 171 mrem per year to the bone (osteocytes).

Besides the natural background radiation, background radiation doses include contributions from man-made or technologically enhanced sources of radiation. By far, the most significant are x-ray and radiopharmaceutical medical examinations. These contribute a population-averaged dose estimated to be 70 mrem per year for the U.S. population as a whole. Fallout from nuclear weapons testing through 1970 has contributed 50-year dose commitments estimated as 80 mrem external, and 30, 20, and 45 mrem internal to the gonads, lung, and bone marrow, respectively. Contributions from the use of fossil fuels (natural gas and coal) and nuclear reactors; mining, milling, and tailings piles; television sets, smoke detectors, and watch dials could be responsible for an additional 5 mrem

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per year, averaged over the U.S. population as a whole. In addition, the use of radiation or radioactivity for scientific, industrial, or medical purposes may cause workers in the industry and, to a lesser extent, members of the general public, to receive some radiation exposure above natural background.

EVALUATION OF RADIATION DOSE AND POTENTIAL HAZARD

Radiation, regardless of its sources, is considered to be a hazard because of its potential for producing adverse effects on human life. Very large amounts of radiation received over a brief period, i.e., hundreds of rem delivered within a few hours, can produce severe injury or death within days or weeks. Distributed over longer intervals, however, these same doses would not cause early illness or fatality. At doses and rates too low to produce these immediate symptoms, chronic or repeated exposure to radiation can bring about biological damage which does not appear until years or decades later. These low-level effects are stochastic in nature; their probability rather than their severity increases with dose. Primary among these latent or delayed effects are somatic effects, where insults such as cancers occur directly to the individual exposed, and genetic defects, where, through damage to the reproductive cells of the exposed individual, disability and disease ranging from subtle to severe are transmitted to the exposed person's offspring.

Clinical or observed evidence of a relationship between radiation and human cancers arise from several sources. The most important data come from the victims of Hiroshima and Nagasaki, patients exposed during medical therapy, radium dial painters, and uranium miners. Data exist only for relatively large doses; there have been no direct measurements of increased incidence of cancer for low-level radiation exposures. Evaluation of the available data has lead to estimates of the risk of radiation-induced cancer; estimated risks for the lower doses have been derived by linear extrapolation from the higher doses. All radiation exposures then, no matter how small, are assumed to be capable of increasing an individual's risk of contracting cancer.

Data on genetic defects resulting from radiation exposure of humans is not available to the extent necessary to allow an estimate of the risk of radiation-induced effects. Data from animals, along with general knowledge of genetics, have been used to derive an estimate of the risks of genetic effects.

Estimates of health effects from radiation doses are usually based on risk factors as provided in reports issued by the International Commission on Radiological Protection (ICRP), National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), or United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Multiplying the estimated dose by the appropriate risk factor provides an estimate of the risk or probability of induction of health effects to an individual or his descendants as a result of that exposure. The evaluation of these risk factors is presently subject to large uncertainties and, therefore, potential continual revision. The risk factors recommended by the ICRP for cancer mortality and hereditary

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(cont'd.)

ill health to the first and second generations are 10^{-4} per rem of whole-body dose and 4×10^{-5} per rem of gonadal dose, respectively. As an example, a whole-body dose of 1 rem would be estimated to add a risk of cancer mortality to the exposed individual of 10^{-4} , i.e., 1 chance in 10,000. However, a precise numerical value cannot be assigned with any certainty to a particular individual's increase in risk attributable to radiation exposure. The reasons for this are numerous and include the following: (1) uncertainties over the influence of the individual's age, state of health, personal habits, family medical history, and previous or concurrent exposure to other cancer-causing agents, (2) the variability in the latent period (time between exposure and physical evidence of disease), and (3) the uncertainty in the risk factor itself.

To be meaningful, an attempt should be made to view such risk estimates in the appropriate context. One useful comparison is with risks encountered in normal life. Another comparison, potentially more useful, is with an estimation of the risks attributable to natural background radiation. Radiation from natural external and internal radioactivity results in the same types of interactions with body tissues as that from "man-made" radioactivity. Hence, the risks from a specified dose are the same regardless of the source. Rather than going through an intermediate step involving risk factors, doses can also be compared directly to natural background radiation doses.

Besides estimation of risks and comparisons to natural background, doses may be compared to standards and regulations. The appropriate standards, the Department of Energy's "Requirements for Radiation Protection," give limits for external and internal exposures for the whole body and specified organs which are expressed as the permissible dose or dose commitment annually in addition to natural background and medical exposures. There are, in general, two sets of limits, one applicable to occupationally exposed persons and the second applicable to individuals and population groups of the general public. The limits for individuals of the public are one-tenth of those permitted for occupationally exposed individuals. The set of limits important to this report are those applicable to individuals and population groups of the public. The limits for individuals of the public are 500 mrem per year to the whole body, gonads, or bone marrow and 1500 mrem per year to other organs. The limits for population groups of the public are 170 mrem to the whole body, gonads, or bone marrow and 500 mrem per year to other organs, averaged over the group. In either case, exposures are to be limited to the lowest levels reasonably achievable within the given limits.

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